Highlights
IN
Space

PROGRESS
IN SPACE SCIENCE, TECHNOLOGY
AND APPLICATIONS

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Highlights in Space

Progress in space science, technology and applications

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FOREWORD

Space activities have become an essential element in improving and enriching our lives and in expanding international cooperation. This review of recent developments in space science, technology and applications is intended to provide information on these important developments to a wide international audience. It is part of the information and education activities being undertaken by the United Nations for International Space Year 1992, which was endorsed by the United Nations General Assembly in 1989 as part of United Nations efforts to promote access by all countries to the benefits of space activities.

During the past year, particular attention has been paid to Earth observation from space for the purpose of monitoring global environmental changes that may pose threats to the well-being of life on Earth. The focus of International Space Year activities on the theme "Mission to Planet Earth" emphasizes the connection between studies of other planets in the solar system and studies of the Earth as a complex natural system. The understanding of our planet and the natural processes that sustain life will help us in the long-term management of our agricultural resources, the water and soil resources that support them, and the mineral resources which provide energy and raw materials.

Advances in other areas of space science, technology and applications are also playing an increasingly important role in economic and social development. Satellites are being used to expand communication networks both nationally and internationally and to promote international cooperation and cultural exchange. Space life-science research in such areas as radiation biology and biomedical technology are providing new techniques for health care on Earth. The results of space research in new materials and microgravity processes is contributing to industrial development in many countries. And space research and space exploration are stimulating our imaginations and enriching our knowledge of ourselves, the world we live in and the universe around us.

I hope that this publication will improve the dissemination of information on space activities and the benefits they provide to all countries and promote international cooperation in space for the benefit of all.

Vladimir Petrovsky
Under-Secretary-General for Political Affairs

INTRODUCTION

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space. The first part of this study, on space technology and applications, was prepared by the International Astronautical Federation (IAF). The second part, on space science, was prepared by Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the foremost international experts from many countries have contributed to this comprehensive and authoritative survey, and the information it contains reflects the wide range of space activities currently being carried out in many national and international space programmes in such fields as space transportation and satellite technology, Earth observations and satellite communications, and studies of other planets, the solar system and the universe. A list of the contributors is to be found at the end of this publication. The publication is being circulated only in the language in which the reports were prepared and submitted.

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HIGHLIGHTS IN SPACE
PROGRESS IN SPACE SCIENCE, TECHNOLOGY AND APPLICATIONS 1991

PART ONE: HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS 1991

I. OVERVIEW

The most significant developments affecting space technology and applications in 1991 were the ever-increasing budget pressures on national space programs, the broadening trend toward commercializing all space activities, the growing emphasis on environmental research and monitoring from space, the continuing expansion of mobile satellite communications applications, and increasing pressures to use smaller spacecraft.

The most profound changes occurred as a result of the political reorganization of the Soviet Union and the Eastern European nations. Although some results are already apparent, such as the surge in marketing of space products and services by the Soviet nations, the longer-term impacts of these changes on both current and future Soviet and Eastern European space activities have yet to evolve.

Important changes in the United States were signaled by the far-reaching December 1990 recommendations of the Committee on the Future of the United States Space Program and the release by President Bush in September 1991 of a new United States' space transportation policy. Responding to budgetary pressures, the United States Congress mandated a major rescoping of Space Station Freedom, a recasting of the Earth Observing System for environmental research and monitoring, indefinite postponement of the Space Exploration Initiative despite the strong recommendations of a prestigious Synthesis Group report, and cutbacks in the early phases of new launch system development.

Similar financial pressures in Germany, Italy, France, the United Kingdom, and all member nations of the European Space Agency have necessitated retrenching in many areas of space development, most notably in the Columbus space station program, the Hermes spaceplane, and other large projects.

The most encouraging advances appeared in the proliferation of new commercial organizations and consortia seeking to broaden space-related services in all market areas, particularly in communications and navigation. The demonstrated value of space capabilities during the Desert Storm operations in Kuwait and Iraq revealed many potential new options for commercial and civil applications, some of which have already appeared on the world market.

Another encouraging note is the success of current space exploration missions, which are returning exciting new data on the Solar System and the Universe at an unprecedented rate, despite mechanical difficulties with both onboard systems and launch vehicles. The "New Golden Age" of scientific spacecraft which began last year appears to be well established and thriving.

II. SPACE TRANSPORTATION

A. Current Launch Activities

The USSR conducted 75 launches in 1990, one more than in 1989, continuing the lower launch rate that stems from improvements in Soviet spacecraft lifetime and capability.

Buran-2 underwent tests on the launch pad during the summer in preparation for the next launch of the winged shuttle, currently planned for late 1992. The Molniya Scientific and Industrial Enterprise has built 5 shuttles. One more (in addition to Buran-2) will be outfitted for space flight, one will be used for ground training, and one will be offered for sale. Buran-1, which flew successfully in November 1988, was primarily a test vehicle and is no longer considered flightworthy.

On 30 August an SL-19 Zenit launcher exploded shortly after launch from the Baikonur Cosmodrome. The failure was not caused by the RD-170 engine, which had been responsible for the previous SL-16 loss in October 1990 that also destroyed the launch pad at Baikonur.

General Dynamics received the first commercial launch operator's license from the United States Department of Transportation on 22 February. The license covers Atlas launch operations from Cape Canaveral for the next two years.

The first launch of a Titan-4 from the United States Western Test Range (WTR) was conducted successfully on 8 March, following three previous Titan-4 launches from the Eastern Test Range (ETR) at Cape Canaveral. Unlike ETR, polar-orbit launches can be made from the WTR. Titan-4 can carry up to 15,000 kg to a 160-km polar orbit. The United States Air Force also announced in July its intent to reactivate a WTR launch pad for Atlas 2 vehicles, which makes possible the launch of medium-size polar-orbit satellites such as those now contemplated for NASA's Earth Observing System (see below).

In June Intelsat contracted with General Dynamics to increase the payload capability of its Atlas 2AS launcher by 121 kg to provide extra on-board propellant for the Intelsat 7 satellites, extending their lifetimes to 16 years. Two Intelsat 7s are scheduled for launch in 1995.

B. Development Activity

The United States initiated preliminary studies of a new National Launch System (NLS) to be developed jointly by NASA and the United States Air Force. It will consist of a family of launch vehicles derived from the Air Force Advanced Launch System and NASA's Space Shuttle, using many common elements; e.g., a 260-kg-thrust hydrogen-oxygen engine, avionics, automated ground-servicing systems, etc. Payloads being considered for the various configurations, some of which employ solid-propellant boosters, range from about 9,000 kg to over 110,000 kg to low Earth orbit. The NLS is a major element in the new United States space transportation policy, announced 24 July, which also rules out the purchase of new Shuttle orbiters after Endeavour. The policy calls for a 10-year launch technology plan to be developed by NASA, the Department of Defense, and the Department of Energy, and also strongly encourages the growth of commercial launch operations.

Conceptual designs for a new United States Personnel Launch System (PLS) are being developed at NASA's Langley Research Center. One preliminary version designated HL-20, based on United States and Soviet lifting-body research, would carry two pilots and 8 passengers to and from Space Station Freedom using Titan-4 and, eventually, NLS-type launchers.

The United States Strategic Defense Initiative Organization awarded a contract in August to McDonnell Douglas for subscale demonstration of a fully recoverable all-rocket single-stage-to-orbit launch concept whose design focus is operational simplicity and quick turnaround. Conceptual designs feature a hydrogen-oxygen segmented plug-nozzle engine driving a conical vehicle with a gross mass of about 400,000 kg and a payload to low Earth orbit of 8,000 kg. Subscale demonstration is scheduled for 1993, using Pratt & Whitney RL-10 A-4 engines modified to ignite at sea level and to incorporate throttling for hovering flight.

Other United States vehicles in various stages of development include General Dynamics' Atlas 2AS, which differs from all previous Atlas vehicles in that it uses small solid-propellant boosters to loft 3,600-kg payloads into geosynchronous transfer orbit.

In September the Ukrainian Yuznoye Design Office announced a new small launch vehicle using refitted SS-24 missile launchers deployed from An-124 aircraft. The "Space Clipper" can carry 500-kg payloads into 600-km orbits.

The European Space Agency development continued on Ariane-5, which will begin to succeed Ariane-4 in 1995. It can launch over 6,800 kg into geosynchronous transfer orbit, compared with Ariane 44L's 4,200-kg payload capability. Many major elements of the Ariane-5 launch facility at Kourou, French Guiana are complete, and component testing (of the Ariane-5 solid-propellant booster) began there late in 1991.

ESA created a unified European program to coordinate several national programs on post-Ariane launch concepts that utilize hypersonic vehicles. The Future European Space Transportation Investigation Program (FESTIP) is planned to begin in 1993. Its goals are to narrow the various hypersonic-vehicle concepts to a single design and to develop technologies that can be used for other applications.

On April 10 Italy's Alenia signed an agreement with Deutsche Aerospace to conduct advanced materials work for the Saenger hypersonic aerospace plane program. Sweden and

Norway had signed previous agreements to participate in Saenger research. Saenger is a two-stage launcher, using an airbreathing first-stage vehicle up to Mach 6.8 and then a second rocket stage to carry a crew of three and 3,000 kg of cargo to low Earth orbit.

Development of Japan's H-2 launch vehicle, designed to carry 2,000-kg payloads to geostationary orbit, is now paced by LE-7 first-stage engine testing (see below), which may delay the vehicle's first launch until 1994. However, in October Japan's launch-service marketing company, Rocket Systems, submitted a bid to launch Inmarsat 3 satellites aboard H-2 rockets, beginning in November 1994. Meanwhile the National Space Development Agency (NASDA) plans to cooperate with the Institute of Space and Astronautical Science (ISAS) to develop a new launcher for 800-kg satellites using components of NASDA's H-2 and ISAS's M-3S2. A major role for the new vehicle would be in testing the HOPE orbiting space plane. On 16 September Japan launched TR-1A (Tagesaki-1), whose two-stage solid-propellant launcher is similar to the H-2's boosters.

C. Other Transportation Services

British Aerospace Australia, Auspace Ltd, and Hawker de Havilland initiated plans in June to work with the Australian government to reopen the Woomera launch range in southern Australia, which was last used for rocket tests in the 1970s. The range offers good access to the polar orbits used by remote-sensing satellites. In the United States, Alaska Aerospace Development Corporation was created in July to promote commercial use of the sounding-rocket Poker Flat Research Range launch site.

Ingosstrakh Ltd. Insurance Company became the first Soviet organization offering to provide insurance for both launch and in-orbit failures. Its first policy, issued in September, covered the launch of a Gorizont communications satellite aboard a Proton launch vehicle.

III. UNMANNED EARTH ORBITAL ACTIVITIES

A. Telecommunications

1. General-Purpose Systems

(a) Europe

On 21 December 1990 the Turkish postal services administration contracted with a team led by France's Aerospatiale to build two Turksat satellites, each carrying 16 Ku-band transponders. The team, which includes France's Alcatel Espace and Germany's MBB, will also provide ground stations and technical assistance. First launch, by Arianespace, is planned for 1993.

An Ariane 44L vehicle successfully launched two European communications satellites on 15 January. Eutelsat 2F2 is the second (of 6) in the Eutelsat-2 series. It carries 16 transponders for television, radio, and business-communication traffic. Italsat 1, built by Selenia Spazio, is

Italy's first national communications satellite. It has 9 transponders for use in advanced telecommunications and improved telephone service, and incorporates onboard switching able to redirect up to 12,000 telephone calls.

Italy also announced a new program for two Primosat spacecraft, financed privately by the Intermercato Group of Lucca, Italy, which will market services in Europe with emphasis on Eastern Europe. Each of the small Primosats will weigh about 940 kg and carry eight active transponders plus two spares. Both launches, by Arianespace, are planned for 1993.

Luxembourg's Astra 1B satellite, with 16 transponders, was launched successfully by an Ariane 44LP on 2 March, along with an ESA Meteosat. The spacecraft provides television service to Western Europe.

A newly funded ESA program includes the experimental ARTEMIS satellite and a data relay satellite system. ARTEMIS will carry three advanced payloads to evaluate optical interorbit links, multibeam broadcast, and S-band multiple access. Being built by a consortium led by Selenia Spazio, it is to be launched in 1994.

The experimental Olympus communications satellite, launched in July 1989, began suffering a loss of power on 28 January when one of its solar panels stopped tracking the sun. Subsequently, on 29 May, the spacecraft tumbled out of control and began drifting eastward out of range of its tracking station at Fucino, Italy. An unprecedented recovery operation was set up by ESA, which was successful in thawing the satellite's frozen fuel without damaging its plumbing, restoring power from its frozen batteries, reestablishing control (the first thruster firings occurred on 26 July), and bringing Olympus back to its proper longitude by mid-August. The spacecraft is now once again fully operational.

(b) Asia

A novel aspect of the launch contract negotiations for the 1200-1300-kg Palapa B4 satellite, scheduled for launch late in 1992, was introduced when Indonesia requested all launch bidders to accept raw materials, mostly oil, for their services instead of cash. All three bidders, Chinese, American, and European, agreed to do so. The four previous Palapas were launched aboard United States Delta rockets.

Satellite Japan Corporation of Tokyo entered the commercial domestic communications market this year, joining two other Japanese companies, Space Communications Corporation and Japanese Communications Satellite Corporation (JCSAT), both also of Tokyo. The new company expects to launch two satellites in 1994. Nippon Telephone and Telegraph Corporation (NTT) requested commercial bids in June for two more domestic communications satellites, called N-STAR, to be launched in April 1995.

Toshiba became the first Japanese firm to bid on systems integration and the bus for a commercial satellite program, offering in May to provide these services for two NTT spacecraft each weighing up to 1800 kg and carrying 11 Ka-band, 8 Ku-band, 6 C-band, and 1 S-band transponders. Toshiba based its bid on experience with Japan's ETS-6 spacecraft to be launched in 1993.

On 18 April NHK's BS-3H direct-broadcast satellite was destroyed when one of the two Centaur engines on its Atlas/Centaur launcher failed to ignite. The failure was later traced to debris in the Centaur propellant pump. It was the first Centaur engine failure in over 140 flights. A replacement satellite, BS-3b, was launched successfully by an H-1 rocket from NASDA's Tanegashima Space Center on 25 August. The 550-kg spacecraft has three 120W broadcast transponders and one spare. It went into operation in geostationary orbit at 110 degrees east longitude in November.

The December 1990 in-orbit failure of NHK's Superbird A was traced to improper operation of the spacecraft's attitude control thruster valves, which allowed all the thrusters' oxidizer to leak away. Superbird E (Superbird A's replacement) is scheduled for launch by Arianespace in January 1992; the originally intended replacement, Superbird B, was lost when its Ariane launcher failed in February 1990.

Nippon Hoso Kyokai (NHK), Japan's public broadcasting system, initiated high-definition television (HDTV) broadcasting eight hours daily on one channel from the BS-3b satellite, launched on 25 August (see above). The HDTV broadcasts will supplement NHK's present direct-broadcast television, which now reaches over 4 million households in Japan, with 10 million expected by 1995. JCSAT also began tests this year of digital radio broadcasting, using its Hughes JCSAT-1 spacecraft. It is the first system to employ both direct radio broadcast to customers and digitized radio signal transmission, which is equal in quality to compact discs.

In April Japan announced a new experimental Communications Broadcasting Technology Satellite program to test new techniques. The 1800-kg spacecraft will be launched in 1997 aboard an H-2 rocket, and will carry transponders to relay data from other spacecraft, including space stations; to transmit Ka-band radio and television programs (including HDTV) to small receiving antennas; and to service mobile receivers with Ka-band voice, data, and television and with millimeter-wave communications.

India's INSAT-2A completed final integrated tests prior to its launch by Arianespace, currently scheduled for March 1992. The second-generation multipurpose satellite weighs 1950 kg and carries 18 C-band transponders, 2 high-power S-band transponders, a Very High Resolution Radiometer for meteorological imaging from the geostationary orbit, and a search-and-rescue payload.

Korea Telecom initiated a two-satellite program to provide domestic telecommunications and direct broadcasting services. The 650-kg satellites are planned for launch in 1995, and will each carry 15 transponders.

Thailand's Shinawatra Computer Company, acting for the Ministry of Transport and Communications, agreed on 10 June to contract with Hughes Space and Communications Group of the United States for construction of two lightweight satellites based on the Hughes HS-376 bus. Each satellite will weigh only 400 kg excluding propellant, and will carry 10 C-band and 2 Ku-band transponders. First launch is planned for 1993.

(c) United States

Alascom's Aurora 2 satellite, launched aboard a United States Delta on 29 May, replaced Aurora 1. The new satellite, which carries over 12 million telephone calls daily, is equipped with 24 C-band transponders.

The first United States license for an audio broadcast satellite was issued on 21 June by the Federal Communications Commission to Worldspace Corporation, which plans to launch its experimental satellite in 1993 on a Chinese rocket. The satellite will be used by Worldspace's subsidiary Afrispace to serve Africa and southwestern Asia.

The fifth Tracking and Data Relay Satellite (TDRS-5) was launched by the crew of Space Shuttle Atlantis on 3 August, and was subsequently moved to its operational position over the Pacific Ocean. Atlantis landed at the Kennedy Space Center's runway in Florida for the first time since 1985.

On 8 September NASA's Office of Commercial Programs selected two Centers for Commercial Development of Space (CCDS) specializing in satellite communications. One of the tasks of the new centers, at the University of Maryland and Florida Atlantic University, will be to garner industry support to develop services and equipment stemming from NASA's Advanced Communications Technology Satellite (ACTS), scheduled for launch in April 1993.

(d) Soviet Union

On 10 April the Soviet Union announced plans to deploy a new series of television broadcast satellites, called Gals, to supplement its present fleet of Ekran spacecraft. Each of the five Gals satellites will carry 3 Ku-band transponders. Two will be located at 44 degrees East longitude; three at 23 degrees East. The new system will be designed for three different types of receiving antenna: one 2.5 m diameter, for office buildings; one 1.5 m diameter, for apartment buildings, and one 0.6-0.9 m diameter, for individual users.

The Soviet Gorizont system will be replaced beginning in 1993 by eleven Express spacecraft. Each of the 2,500-kg satellites will carry ten 15W C-band and two 60W Ku-band transponders. Total power per satellite is 2.4 kW

In September Russia's Astra signed an agreement with Italy's Telespazio to create Astelit, a joint venture using Soviet Raduga geostationary military communications satellites with Italcable's network to provide international telephone and videoconferencing services to Western businesses working in the Soviet nations. Agreements were also signed by Telespazio with the Soviet firm Planeta and the government agency Agroresources to market remote-sensing data from Soviet spacecraft and introduce Italian computer technology into Soviet data-processing.

(e) Other Countries

The two satellites comprising Canada's fifth-generation Anik E series were launched aboard Ariane 44P rockets this year, Anik E-2 on 4 April and Anik E-1 on 26 September. The two 2,900-kg satellites carry a total of 24 12W C-band transponders plus 6 spares and 16 50W Ku-band transponders plus two spares. They are expected to serve Canada's needs until beyond the turn of the century. E2 suffered an antenna deployment problem on 12 April, but it was successfully deployed on 3 July by herculean efforts on the part of the Anik ground-control team. It went into service on 1 September.

On 19 March Mexico selected Hughes Space and Communications Group to build two Solidaridad satellites. The 1600-kg spacecraft will use the Hughes HS-601 bus and will be equipped with an L-band transponder for mobile communications capability as well as 18 C-band and 16 Ku-band fixed-service transponders. Arianespace was selected on 19 July to launch the satellites in 1994.

Israel's first commercial domestic satellite program, AMOS, was announced in March to be a two-satellite system with 12 Ku-band transponders for telephone, telex, facsimile, and television service, including direct broadcasting to 1-m receiving antennas. Israel Aircraft Industries will build the satellites, the first of which is planned for launch in 1994.

(f) International

In May an alliance to design, manufacture and market commercial satellites was formed by Deutsche Aerospace, France's Alcatel and Aerospatiale, Italy's Alenia, and Loral Space Systems of the United States. The new consortium will coordinate bids on satellite contracts and share manufacturing activities.

The Soviet Union became the 121st member of Intelsat, and also signed a memo of understanding with Intelsat's board of governors to increase cooperation between Intelsat and Intersputnik aimed ultimately at merging the two international networks.

On 14 August an Ariane 44L booster launched the fourth (of five) satellites in the Intelsat 6 series. The 4,250-kg spacecraft carries 38 C-band and 10 Ku-band transponders for use in the high-traffic Atlantic Ocean region. In October Intelsat also announced, for the first time, access to its system on an experimental monthly basis for digital audio distribution services by all member nations.

In August Alpha Lyracom (formerly PanAmSat) signed agreements with Hughes Communications (United States) and the Great Wall Industry Corporation (China) to build and launch ORBX 1,2, and 3 aboard Long March rockets. The first launch is scheduled for early 1994. Great Wall will also buy services from Alpha Lyracom for domestic and Southeast Asia international communications. Alpha Lyracom's privately owned international constellation will offer a total of 72 C-band and 72 Ku-band transponders.

2. Mobile Systems

Inmarsat-C portable-communicator service was initiated in the Pacific region on 4 January and in the eastern Atlantic area on 17 January. Inmarsat-C is a suitcase-sized unit that allows mobile users to communicate via the 9 Inmarsat satellites. The first commercial telephone call to use this service was placed by a passenger aboard a Singapore Airlines Boeing 747 on 25 September. Twelve ground stations installed this year will extend service to customers on a global basis. Besides communications, Inmarsat-C users will have access to tracking and position-location services via the United States Global Positioning System.

Two major United States truck fleets, one with 2,150 vehicles, the other with 370, began using Qualcomm messaging and position-location services employing mobile units called OmniTRACS in all their vehicles.

On 1 February Inmarsat contracted with GE AstroSpace in the United States to build 4 Inmarsat-3 satellites, which will be the first to incorporate navigation capability using the Global Positioning System. England's Marconi Space Systems is a subcontractor in the US$320-million procurement. The second Inmarsat-2 satellite was launched successfully by a United States Delta-2 on 8 March; it went into service over the Atlantic Ocean (at 15.5 degrees West longitude) on 13 April. On April 9th, Iceland became Inmarsat's 64th member, and will use the Inmarsat Hooksat project for dedicated communications among Iceland's fishing fleet.

ESA proposed development of Archimedes, a new system of three satellites in Molniya orbits (elliptical orbits with high apogees, typically 40,000 km, and low perigees, around 600 km), for users in automobiles, planes, and trains. ESA's role would be to build, launch, and test one of the three satellites late in the 1990s; a commercial enterprise would then complete and operate the system. Launch into the required high-inclination orbit would be most efficient from the Soviet Baikonur Cosmodrome.

Canada's Telesat Mobile, Inc. contracted with Arianespace in June to launch its MSAT-1 satellite in 1994. The companion Mobile Satellite Corporation (United States) spacecraft is as yet uncommitted to a launch firm. Both satellites are being manufactured by a Hughes-Spar Aerospace team.

The Soviet Union announced a new mobile communications system called Marathon, to be operated commercially by a consortium of Soviet companies. It will use two different types of satellites: three Arkos geostationary-orbit spacecraft and two to four Mayak satellites in Molniya orbits for Arctic coverage.

3. Navigation and Position Location

Operation Desert Storm demonstrated the extreme versatility and applicability of the United States Global Positioning System (GPS) to mobile surface units, including individual soldiers. Over 5,000 commercially built receivers were distributed and used to pinpoint locations in the trackless desert terrain. In July Japan's Sony Corporation began marketing 600-gram GPS receivers (including batteries) designated PYXIS IPS-360, priced at US$1,150, to recreational users such as boat owners, mountain climbers, ultralight and hang-glider pilots, etc. Commercial GPS receivers are also available from the United States firms Magellan Systems Corporation and Trimble Navigation.

A unique use of the GPS was highlighted by the establishment on 1 March of the Southern California Earthquake Center in the United States, which will create a system to measure movements in the Earth's surface of less than 1 cm by continuous monitoring of the distance between many GPS receivers.

On 1 April a United States Northwest Airlines aircraft conducted the first flight test of a cooperative venture to combine use of the United States Global Positioning System (GPS - currently 15 satellites) and the Soviet Globol Orbiting Navigation Satellite System (GLONASS - currently 12 satellites). The purpose of the test was to demonstrate operation of both systems using the same radio signal. Both the United States and the Soviet Union have offered the use of their satellite navigation signals at no cost to all airlines.

In May the United States company Geostar, which had pioneered Radio Determination Satellite Service (RDSS) for position location, terminated operations and liquidated its assets to pay off creditors. Former Geostar customers switched to Qualcomm, which currently has about 15,000 users in the United States. The French firm Locstar also terminated its operations in July because of inability to secure financing, leaving the estimated 50,000-unit European market to Eutelsat's RDSS division Euteltracs, which uses Qualcomm equipment, and to the Inmarsat-C service (see above).

B. Earth Observations

All three commercial remote-sensing organizations demonstrated the value of their technology during Operation Desert Storm in Kuwait and Iraq. Images offered by Eosat (United States), Spotimage (France), and Soyuzkarta (Soviet) often provided the only available data in the region for both military and non-military purposes. The high resolution of the Soviet KFA-1000 camera (sometimes as good as 3-m) was particularly noteworthy, although the need to retrieve the entire camera before making data available impeded somewhat its timely dissemination.

In August the United States Earth Observing System (EOS), to be launched late in the decade, was recast by dividing its six major multi-instrument platforms into 18 medium-sized satellites, each carrying about a third of the instruments planned for the original large 13,300-kg platforms. The smaller spacecraft, which would be comparable in scale to the Upper Atmosphere Research Satellite (see below), can be launched by Atlas 2AS boosters from the Western Test Range (see above) instead of having to use large Titan-4 vehicles. The small Earth Probes spacecraft originally planned to be part of EOS remain an essential part of the recast program, but pressure has also been exerted to redesign the EOS Data and Information System (EOSDIS) to accommodate new systems approaches and technologies.

The 6,800-kg United States Upper Atmosphere Research Satellite (UARS), often called the first step in "Mission to Planet Earth," was launched by Space Shuttle Discovery on 12 September. Its 10 instruments will provide detailed data on chemical processes in the upper atmosphere from 15 to 120 km altitude, focusing particularly on anthropogenic effects. UARS is the first spacecraft equipped to determine the interaction of the atmosphere's chemical reactions with winds and solar radiation. The spacecraft was built by GE AstroSpace, but scientists, engineers, and contractors from Canada, France, Germany, Italy, and the United Kingdom are major participants in its design, construction, and use. About a hundred scientists will also conduct ground and aircraft-based atmospheric measurements to complement the spacecraft's observations.

China launched a Weaver Girl 3 sounding rocket on 22 January to measure atmospheric data at 120-km altitude. The data are for use in designing space launchers and other space vehicles.

Data from the Total Ozone Mapping Spectrometer (TOMS) on the United States Nimbus-7 satellite recorded the second largest and longest-lasting Antarctic ozone hole in history, ending in late December 1990. A new TOMS instrument was launched from the Plesetsk Cosmodrome aboard a Soviet Meteor-3 spacecraft in August 1991 to continue and expand stratospheric ozone data collection, shortly following the signing by Presidents Bush and Gorbachev of a far-reaching agreement on cooperation in environmental monitoring from space. It was the first United States science instrument to fly aboard a Soviet unmanned satellite.

Concerns about stratospheric ozone depletion have stimulated several advanced-technology options for replenishing the ozone, including an ozone generator deployed by a tether from a spacecraft down into the ionosphere, an orbiting chemical system to react with chlorine atoms (which destroy ozone), chlorine neutralization or ozone generation by lasers, and conversion of neutral chlorine molecules to negative ions by microwave or charged-particle beams

On 27 February the United States and Canada signed an agreement to cooperate in the launch, operation, and use of Canada's Radarsat, planned to begin mapping the Earth's polar regions in 1994. The spacecraft is being built by Canada's Spar Aerospace. In April Italy's Telespazio and the Soviet agency Agroresources agreed to work jointly on agricultural remote-sensing programs, supplementing Telespazio's prior agreement for remote-sensing development with the Soviet Planeta agency. On 10 April, Hungary and ESA signed an agreement to exchange information on space-based environmental monitoring, as well as on telecommunications and space science.

Four Canadian companies, MacDonald Dettwiler, Bristol Aerospace, Intera Technologies, and SED Systems, completed in August a definition study of a remote-sensing satellite series designated Keysat. The first Keysat spacecraft, GreenSpace, will focus on vegetation and water-related targets. No firm launch schedule has been established.

Japan's Earth Resources Satellite Data Analysis Center initiated a major program to map the Earth's geologic features, including mineral deposits, using the ERS-1 satellite scheduled for launch in February 1992 aboard an H-1 rocket. The Center has begun development of the computer software needed to create a global geological map by 1997. ERS-1 will be Japan's entry into the commercial remote-sensing market; it will be equipped with synthetic-aperture radar for all-weather imagery. ERS-1 will be followed in 1995 by the 3,000-kg Advanced Earth Observing Satellite, to be launched by an H-2, which will carry one French and two NASA sensors. A third satellite, which is expected to complement the United States Earth Observing System, is expected to be launched on an H-2 in 1998 or 1999.

ESA's Meteosat Operational Program (MOP-2) satellite was launched by an Ariane 44LP on 2 March, along with Luxembourg's Astra 1B. It is the second of three in the series. In cooperation with the European Community, ESA has set up three major programs for obtaining environmental data through Earth observations. One of these, called TREES, focuses on assessing global forest damage; the second, named European Airborne Remote Sensing Capabilities, will develop all-weather airborne radar to complement and validate radar data from the ERS-1 and ERS-2 satellites (see below); the third is the Ocean Color Environmental Archive Network, which will analyze ocean plankton content and algae blooms.

In September Eumetsat agreed to lend the United States a spare ESA Meteosat-3 spacecraft until the United States Geostationary Operational Environmental Satellite (GOES-Next) can be readied for launch. GOES-Next has been delayed for a year (launch is now expected no sooner than 1993) due to development problems with its advanced sensor equipment, and the present GOES-7 is expected to cease operating late in 1992. Meteosat-3 will be moved further west (it was used in late August to monitor Hurricane Bob's movement up the east coastof the United States), so its current operation by Eumetsat's Darmstadt, Germany, control center will be supplemented by a new United States ground station at Wallops Island, Virginia.

On 31 March the Soviet Union launched Almaz, the first commercial radar satellite, aboard a Proton rocket. Its data supplement those available from the United States Landsat and the French Spot in that its radar can penetrate clouds, measure soil moisture and surface roughness, and map underwater terrain to 15-m resolution. The USSR also launched a new Resurs-F satellite on 21 May, carrying an MK-4 camera whose images, recovered with the camera in July, were marketed commercially.

In April Brazil requested bids to launch its small 115-kg environmental data relay spacecraft (Satellite de Coleta de Dados 1, or SCD-1) from Alcantara, a new launch site under construction at 2 degrees south latitude. Competitors are the United States Pegasus, the United States Scout, the Soviet Vysota, and a small Chinese rocket.

The United States NOAA-12 satellite, launched 14 May aboard an Atlas-E, joined two previous NOAA spacecraft in using its Advanced Very High Resolution Radiometer (AVHRR) to measure and monitor the severe drought conditions in sub-Saharan Sudan, where there are no ground-based weather stations. NOAA-12 is now making similar measurements in southeast Asia. The data are useful in predicting agricultural yields.

ESA's ERS-1 environmental satellite was launched into its 800-km polar orbit by Arianespace on 16 July. Its radar altimeter and synthetic aperture radar, both operating superbly to date, extend environmental remote-sensing capability substantially over that of existing systems. Its orbit is being determined with unprecedented precision by a Dutch mobile laser ranging system and stationary European lasers, and ERS-1 will test for the first time a microwave ranging system consisting of the space-based Precise Range and Range Rate Equipmet (PRARE) and a global network of 30 automated ground stations. ERS-2, to be launched in late 1994, will include a Global Ozone Monitoring Experiment.

India's second remote-sensing satellite, the 980-kg IRS-1B, was launched into its 904-km polar orbit on 29 August by a Soviet Vostok from Baikonur Cosmodrome. Two linear imaging self-scanning cameras collect Earth data in the blue, green, red, and infrared spectral bands with 36 and 72-m resolution. Unlike its predecessor, IRS-1A, which transmits only to ground stations in India, data from IRS-1B will be made available on a commercial basis to ground stations in other countries. IRS-1A and 1B provide vital services in agriculture, land and water resources, forestry, wasteland delineation, ocean development, soil monitoring, and drought and flood management.

C. Small Satellites

The United States firms Motorola and Lockheed signed an agreement in March that designates Lockheed as the bus developer for the 77-spacecraft Iridium constellation for global cellular-telephone service, with Motorola responsible for the communications payload. The L-band Main Mission Antenna system was assigned on 31 July to the Raytheon Corporation. The satellites will be deployed at an altitude of 760 km in seven orbital planes. Several United States competitors to Iridium have since filed requests for licenses from the United States Federal Communications Commission: Ellipsat (an 18-satellite constellation of small, 180-kg L-band spacecraft in three orbits); Constellation Communications' Aries system (48 125-kg satellites in four 1,000-km orbits); Loral Qualcomm Satellite Services' Globalstar (also 48 small satellites); and TRW's 12-satellite constellation of 1150-kg spacecraft. Hughes Aircraft also proposed, but did not file for, a system called Tritium, consisting of three 1600-kg satellites orbiting 120 degrees apart. The United States Federal Communications Commission (FCC) on 26 September allocated specific spectrum ranges to low-Earth-orbit satellite constellations and recommended that the 1992 World Administrative Radio Conference (WARC-92) approve international spectrum allocations for this use.

On 26 March the international Consortium of Small Satellite Constructors and Service Providers, headquartered in Moscow, announced a plan to launch 24 to 36 small (70-kg) satellites to 1600 km orbits in four orbital planes. The Gonets satellites, employing well-proven Soviet military spacecraft technology, will be launched by Soviet Cyclone rockets, and will provide electronic mail, voice mail, facsimile, position location, and telemetry services. The Soviets are also planning a system called Coscon, to be developed by NPO Polyot. It consist of 32 600-kg satellites in four 1,000-km orbital planes at 83 degrees inclination. Coscon, too, is based on a current satellite type: the Informator 1 data-collection spacecraft launched on 29 January.

On 3 July Ball Aerospace (United States) flew its prototype Quickstar small satellite bus as a secondary payload on a United States Delta launcher. The bus is being offered to customers with 20-25 kg payloads. It has a volume of about 0.05 cubic meter, a gallium arsenide power panel with an area of about 1.1 square meters, can store about 0.5 gigabits of information, and can remain in orbit 3 months to a year. The prototype cost US$2.5 million, including launch.

The United States Pegasus, built by Orbital Sciences Corporation, launched 7 "Microsats" into a lower-than-planned orbit on 17 July. The 22-kg spacecraft, designed to evaluate for the Defense Advanced Research Projects Agency (DARPA) the usefulness of small ultra-high-frequency communications satellites to tactical military commanders in the field, are in 350-450-km orbits instead of the planned 715-km orbit, so they will last only about one year instead of three, and will not be able to provide continuous coverage as planned.

On 16 July Arianespace launched four small satellites as an auxiliary payload aboard the Ariane 4 that launched Europe's ERS-1 (see above). One was a 50-kg research satellite, UoSat-5, built by Surrey Satellite Technology of the British University of Surrey to photograph the Earth (it took excellent pictures of the burning Kuwait oil fields), to study the effects of radiation on semiconductors and gallium arsenide solar cells, and to serve as an orbiting relay for HealthNet, used by developing-nation hospitals and disaster relief operations. The 22-35-kg SARA and TUBSAT spacecraft were built by students at the French Ecole Superieure d'Ingenieurs en Electronique and at the Technical University of Berlin, respectively. SARA monitors radioemissions from Jupiter, to complement data from Ulysses and Galileo, and TUBSAT tests communication systems for remote expeditions. The fourth smallsat, 16-kg Orbcomm-X, was built by Orbital Sciences Corporation's Orbcomm division to evaluate the practicality of a commercial 20-satellite data transmission network. Contact with Orbcomm-X was lost on 22 July.

A student team from South Africa's University of Stellenbosch announced plans to develop and fly a small satellite called Sunsat. It would weigh about 50 kg, develop about 100W from its solar panels, and use three-axis attitude control. It would be placed in a Sun-synchronous 800-km orbit, and could be ready for launch as an auxiliary Ariane payload in 1994. Possible payload options include a ranging system for position location, stereo Earth observations, amateur-radio voice and digital communications, and communications with the ground control center at Stellenbosch. The concept is patterned after the University of Surrey's UoSat program.

IV. MANNED EARTH ORBITAL ACTIVITIES

A. Space Stations

1. The Soviet Mir

The space station has been successful in maintaining its pointing accuracy of about 1 arc minute, using an attitude control system based on a magnetically suspended controlled momentum wheel (Gyrodyne) with a maximum angular momentum of 1000 N-m-seconds.

A Japanese journalist, Toyohiro Akiyama, spent eight days aboard Mir from 2 to 10 December, 1990. The first journalist in space, Akiyama is news director of the Tokyo Broadcasting System (TBS). He joined Soviet cosmonauts Musa Manarov and Viktor Afanasyev in conducting medical and biological experiments and made daily live broadcasts on his experiences to TBS television viewers. TBS paid US$12 million for Akiyama's training and flight.

Two French astronauts, Michel Tognini and Jean-Pierre Haignere, began training at the Soviet Union's Star City on 8 January for an 8-day mission in summer 1992 designated "Antares." The French space agency CNES will pay US$12 million for the training and for the flight of one French astronaut on the mission. Two German astronauts, Klaus Dietrich Flade and Reinhold Ewald, have been at Star City since mid-1990, training for a 12-day Mir mission also planned for 1992 and costing about US$14.2 million.

On 25 April Soviet cosmonauts Viktor Afanasyev and Musa Manarov went outside Mir to conduct experiments on space construction techniques and to inspect a malfunctioning antenna that had caused docking problems during a Progress resupply mission on 26 March. The follow-on team of Mir cosmonauts, Anatoly Artsebarsky and Sergei Krikalev, repaired Kvant-1's docking module and installed a United States-Soviet cosmic-ray instrument during spacewalks on 25 and 29 June. They subsequently erected a 14-m tower called Sofora on the Kvant 1 module during spacewalks on 15, 19, 23, and 27 July. Sofora was assembled from 20 prefabricated girders using titanium-nickel "shrink" fasteners designed specifically for in-space assemblies. Besides its value as a space construction experiment, Sofora will also be used as a thruster mount to provide more effective attitude control for Mir.

A British research chemist, Helen Sharman, joined Soviet cosmonauts Anatoli Artsebarsky and Sergei Krikalev aboard Mir to conduct about 20 experiments during an 8-day mission called "Juno," launched on 18 May. An Austrian, Franz Viehboeck, was launched to Mir aboard Soyuz TM-13 on 2 October, along with Russian cosmonaut Alexander Volkov and the first Kazakhstan cosmonaut, Toktar Aubakirov. The Austrian and the Kazakh returned to Earth on 10 October with Artsebarsky, who had been aboard Mir since May.

The Soviet Union announced in April that plans for Mir 2 had been scaled back from the original four-module, 100,000-kg configuration. Mir 2 will now consist of a new central module, with Mir-1's existing modules attached to it.

2. Space Station Freedom

Budget concerns in the United States and Europe resulted in a scaleback of Freedom's capabilities and schedule. Current plans call for "human-tended" capability early in 1997, with a single, shortened United States-built laboratory module holding eight (instead of 20) experiment racks, Canada's Mobile Service Center, and 18.75 kW of power (10 kW available to users) instead of 75 kW. The Shuttle will provide life support for up to 13 days at a time. Permanently manned capability will not occur before 2000, when the full 75 kW will be available along with a shortened habitability module that accommodates 4 instead of 8 crew members, the European pressurized Columbus laboratory module, and the Japanese Experiment Module.

On 3 May Italy announced selection of five astronaut candidates for the Freedom-Hermes-Columbus program: Maurizio Cheli, Franco Ongaro, Stefano Santonico, Roberto Tacchino, and Luca Urbani.

B. The Space Shuttle

The United States Space Shuttle fleet flew 7 missions in 1991. 8 are planned for 1992, when the fourth orbiter, Endeavour, will join the fleet (see below).

The Astro science payload of one X-ray and three ultraviolet telescopes returned to Earth a day early, on 11 December 1990, due to weather constraints after a 9-day flight. Although problems with the automatic pointing-system software and the onboard data display units for all the ultraviolet telescopes limited their data collection to 140 of the 250 planned targets, scientists were elated with the quality and quantity of data, which included the discovery of hundreds of hot, energetic young stars in the Magellanic Cloud galaxy and the finding of violent stellar winds surrounding the large Wolf-Rayet class of stars. Indeed, Astro was so successful that earlier plans to terminate the program were revised, and a second Astro flight is now planned for 1993.

On 8 April Shuttle astronauts Jerry Ross and Jay Apt successfully released a jammed antenna on the Gamma Ray Observatory, which made its successful launch possible (see below). On a subsequent spacewalk the following day they also conducted tests of personnel carts and construction methods for space station Freedom.

The new Shuttle Orbiter Endeavour, which will replace the Challenger Orbiter lost in January 1986, was rolled out of the Rockwell International plant in Palmdale California on 25 April. Endeavor was delivered by Rockwell to NASA on time and US$40 million below its budgeted cost. Endeavour's first mission, in April 1992, will be to rescue the 4,000-kg Intelsat 6-F3 satellite stranded in orbit by its Titan booster in March 1990.

C. Other Manned Orbital Programs

Presidents Bush and Gorbachev signed an agreement in Moscow on 31 July to fly Soviet cosmonauts on Shuttle flights and American astronauts on Mir. The first missions could be conducted as early as 1992.

Salyut 7, the present Soviet Mir's predecessor, reentered the atmosphere and broke up over Argentina on 7 February. Deorbiting of the abandoned 40,000-kg space station occurred prematurely due to a fourfold increase in atmospheric density generated by unusually high solar flare activity. Salyut 7 was launched in 1982 and last inhabited by cosmonauts in 1986. The debris which reached Earth fell in unpopulated areas and caused no injuries or damage.

The European Space Agency (ESA) initiated a study by three companies, Aerospatiale of France, British Aerospace, and Belgium's Space Applications Services, to evaluate an automated logistics vehicle, Love, that would carry payloads from launchers such as Ariane 5 to space stations subsequent to Freedom.

All major test objectives were completed in June, a month ahead of schedule, on the joint Italian-United States Tethered Satellite System (TSS) program scheduled for launch on United States Shuttle Atlantis in August 1992. The satellite was built by Aeritalia, now merged with Selenia to form Alenia Spazio as of 1 March; the 20-km deploying system was built by Martin Marietta. Goals of the experiment with the 520-kg, 1.6-m-diameter satellite are to demonstrate the feasibility of placing tethered payloads into orbit, demonstrating maneuverability, and conducting electrodynamic studies of the Earth's ionosphere and magnetic field.

The ESA Hermes program to develop a manned spaceplane carried by Ariane 5 was reprogrammed this year to reduce the number of vehicles built this decade from two to one and to reduce its initial flight rate from twice to once annually. The spaceplane (at 48,800 kg) is also currently overweight by about 2,000 kg, a concern that will be resolved by design improvements or by cutting its payload and increasing Ariane-5's capability.

D. Life Sciences Research

The United States Spacelab Life Sciences flight 5-14 June aboard Space Shuttle Columbia focused on precise measurements of the astronauts' hearts, vestibular systems, metabolism, and hormone levels. Medical specialists James Bagian, Drew Gaffney, Millie Hughes-Fulford, and Rhea Seddon also tested systems for medical operations on Space Station Freedom. One surprising result of the research was that physiological changes due to weightlessness occurred very quickly, as indicated by shifts in blood volume from the legs to the upper torso, increased heart rate, reduced liquid and food consumption, weight loss, reduction in total plasma volume, and motion sickness. Test results also suggested a revision in lung function theory and a prospect that sensory conflict in the brain, which causes motion sickness, may be able to be resolved.

V. SPACE EXPLORATION

A. Unmanned Systems

NASA's Galileo spacecraft received a gravity-assist boost from Earth in December 1990, dipping down to 952 km over the Southern Hemisphere. During the encounter Galileo's instruments were tested by taking infrared and visual images of Antarctica and Australia, making measurements of atmospheric constituents, and photographing the far side of the Moon. A second gravity-assist from Earth is scheduled for December 1992. Efforts to deploy the spacecraft's jammed main communications antenna by thermally shrinking it with a "cold soak" were unsuccessful, and more strenuous efforts such as shaking, rattling, or colder "soaks" will be attempted after Galileo's forthcoming encounter with the asteroid Gaspra (see below). One possible cause of the problem was the extra round trip on the ground that the spacecraft underwent between JPL in California and the Kennedy Space Center in Florida due to the Shuttle Challenger's failure in 1986, which may have rubbed off the lubricant on the pins that held the antenna in its closed position. Without the 134,000 bps transmission capability of the unfurled antenna, Galileo's low-gain antenna's 10 bps transmission rate will preclude most data reception from the Jupiter orbiter, but would allow data to be received from the Jupiter atmosphere probes.

Germany signed an agreement with the Soviet Union on 16 January to provide two cameras and a gigabit computer memory for the Soviet Mars 94 mission. The Soviet Union has reprogrammed the mission to postpone until 1996 the second Phobos vehicle flight, which will carry a rover and balloons designed by French and United States engineers to explore the Martian surface. In tests of the balloons conducted in September from the Norwegian Andoya Range, one of the three balloons launched operated as planned; the other two did not reach the necessary altitude.

The United States Magellan spacecraft completed its first radar mapping cycle of Venus in May, covering about 84% of the surface. A random computer failure in March was quickly corrected by ground controllers, but excessive solar heating of the spacecraft required occasional use of the antenna as a Sun shield, reducing slightly the time available for mapping. In general, the spacecraft performed magnificently, providing data of unprecedented quality on folded rock formations, past volcanic activity, and unusual crater features. Observations made in August suggest that Venus may still be geologically alive, because images made at different times appear to show changes that could be due to a Venusquake and its resulting landslides.

The United States Gamma Ray Observatory (GRO), the second of the four Great Observatories, was launched aboard Space Shuttle Atlantis on 5 April. The 16,000-kg GRO, the heaviest civil payload ever carried into space by the Shuttle, carries four independent instruments to measure such phenomena as intense gamma-ray bursts and the heavy-particle radiation produced by supernovas and black holes. The spacecraft was built by TRW Space and Technology Group under contract to NASA. Initial experiments for the spacecraft's four instruments focused on observations of the Crab nebula, a binary black-hole candidate star named Cygnus X-1, gamma-ray bursts, several pulsars, and intense solar-flare activity. In June GRO's Energetic Gamma Ray Experiment Telescope (EGRET) detected the most distant and by far the most powerful gamma-ray source ever seen: 7 billion light-years distant with an energy 10 million times that of our own Milky Way galaxy. GRO also sparked a major reexamination of the theory behind cosmic-ray bursts when the first four months of data from its Burst and Transient Source Experiment (BATSE) revealed 117 bursts randomly distributed in all directions and distances rather than the neutron-star bursts limited to the Milky Way galaxy that had been observed previously.

In April NASA announced that the troubled Hubble telescope was capturing nine out of ten of its science targets, after software partly correcting the jitter due to solar heating effects on its power arrays had been emplaced in the spacecraft's computers. Plans for a 1993 Shuttle repair mission, long scheduled as part of the original Hubble Telescope program to replace the wide-field camera, now call for replacing the solar panels, installing a Corrective Optics Space Telescope Axial Replacement (COSTAR) to correct the spherical aberration caused by improper grinding of the primary mirror, and replacing the spacecraft's gyroscopes, two of which have failed.

Among Hubble's discoveries this year were detection of planetlike masses of ionized iron circling the star Beta Pictoris, large intergalactic clouds of hydrogen, a unique jet of material issuing from the large unstable star Eta Carinae, a high concentration of young "blue straggler" stars in the cluster 47 Tucanae that appear to result from collisions of old red giants, the ring left by the exploded star Supernova 1987A, and accurate measurement of the distance to the Large Magellanic Cloud.

On 18 April NASA's Lewis Research Center announced that the Solar and Heliospheric Observatory (SOHO) will be launched by a General Dynamics Atlas 2AS rocket in July 1995. SOHO is part of the International Solar and Terrestrial Physics program, a joint effort by ESA, Japan, and the United States. It will study the factors that affect the solar corona and the interior solar structure from its 1.6-million-km orbit during a projected service life of 2 years

On 2 July NASA announced plans for a new Discovery Program to rendezvous with and study several Earth-approaching asteroids. The first mission, Near Earth Asteroid Rendezvous (NEAR), could be launched aboard a Delta 2 as early as 1997. Possible targets include 1943 Anteros in July 1988, and 1982XB in November 1999.

In July ESA's Giotto spacecraft, which photographed the nucleus of Halley's Comet in 1986, was reactivated and sent to meet Comet Grigg Skjellerup in July 1992. Also in July the United States Galileo spacecraft, on its long ride to Jupiter, was guided toward the asteroid Gaspra, which it flew past on 29 October. Data from the encounter were stored, and will be transmitted over the high-gain antenna if it is subsequently deployed successfully. If not, the Gaspra data will be sent to Earth using Galileo's low-gain antenna during the spacecraft's second Earth gravity-assist in December 1992.

On 21 August the European Ulysses spacecraft passed behind the Sun relative to Earth, offering an excellent opportunity to study the corona using the radio interference caused by the conjunction. The spacecraft will make a close approach to Jupiter (375,000 km) in February 1992, using the gravity assist gained from the massive planet to swing it into a heliocentric polar orbit.

Significant advances were made this year in the technology required for detection of other planetary systems using radio, infrared, and optical astronomical methods. In addition to the abovementioned discovery of a pseudoplanet by the Hubble telescope, British radioastronomers at Jodrell Bank claimed to have discovered a planet orbiting a pulsar.

Supplementing ongoing United States programs in SETI, the Search for Extraterrestrial Intelligence (SERENDIP, Ohio State University, and Harvard University), new programs were begun this year at the Argentine Radio Observatory and by the University of Western Australia and CSIRO with the Parkes telescope. Soviet astronomers at Samarkand plan to conduct "magic frequency" searches at the positronium line, 203.385 GHz, and to initiate a search strategy which looks at stars when they are in opposition from the Sun using multichannel spectrum analyzers. Construction of instruments for NASA's Microwave Observing Project that can detect drifting and pulsed signals is nearing completion.

In August the United States and Argentina signed an agreement to to conduct joint research in Earth and space sciences. The first joint mission to be undertaken by NASA with a Latin American country is the Satelite de Aplicaciones Cientificas-B (SAC-B), which will measure high-energy and hard X-ray emissions from solar flares and cosmic-ray burst sources. The Argentine National Commission on Space Activities will build the spacecraft, and Penn State University will build the X-ray cosmic background instrument.

B. Manned Systems

A major milestone in planning the United States Space Exploration Initiative was the release on 11 June of the study conducted for Vice-President Quayle by a special Synthesis Group, led by former United States astronaut Thomas Stafford. The study suggested four possible scenarios for a long-term program designed to establish and maintain bases on the Moon and Mars. Key technologies identified by the report were a heavy-lift launch vehicle (i.e., up to 140,000 kg to low Earth orbit) and the use of nuclear thermal propulsion to reduce trip time between Earth and Mars orbits. The Synthesis Group reviewed over 2500 ideas and concepts submitted in response to a nationwide solicitation, including 550 received and assessed by the American Institute of Aeronautics and Astronautics.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

After a successful 350-second test in February, Japan experienced a series of difficulties in developing the 100,000-kg-thrust liquid-propellant LE-7 engine for its new H-2 launch vehicle, which may necessitate postponing the first H-2 launch until 1994. Successful tests of Nissan's H-2 solid-propellant booster, however, completed in May, marked transition to production of the boosters.

The Solid Rocket Motor Upgrade for the United States Titan 4 exploded on its first test in April, due to a propellant design flaw. The motor's builder, Hercules, plans to test a proposed design modification in subscale tests on 1-m motors.

On 24 June the Soviet Union announced development of a new dual-fuel engine, RD-701, which employs first kerosene and then liquid hydrogen as fuels, with liquid oxygen as the oxidizer. Dual-fuel systems were actively researched by the United States in the 1970s but never flown.

On 28 August the scaled-down Advanced Solid Rocket Motor (ASRM) for the United States Space Shuttle was successfully tested for 30 seconds. This was the first of five scheduled tests on the 8-m motor; a second test of the 18,000-kg test motor (on 26 September) was also successful.

During 1991 India tested and qualified the 125-tonne solid-propellant booster for the Polar Satellite Launch Vehicle (PSLV), scheduled for first launch in 1992. The PSLV's second-stage propulsion system, a 37.5-tonne liquid-propellant engine employing unsymmetrical dimethyl hydrazine and nitrogen tetroxide propellants, was also tested successfully, as were the PSLV's third and fourth-stage motors. India has also tested a 1-tonne cryogenic engine, and is now building its successor, a 12-ton hydrogen-oxygen engine to be used as the third stage of the PSLV, boosting its payload capability to 2,500 kg into geosynchronous transfer orbit.

B. Power

In January the Soviet Union sold a complete unfueled Topaz-2 nuclear space power reactor to the United States for evaluation and study, to aid United States agencies in developing future thermionic power conversion systems for use in nuclear space powerplants. The United States Space Exploration Initiative has rejuvenated United States interest in both nuclear thermal rockets and nuclear-electric propulsion, and a number of new study programs on these systems were initiated this year in the United States.

1991 saw a resurgence of interest in power satellites. An international symposium, "Power from Space," held in Paris during August, concluded that energy and environmental requirements for the 21st century, combined with major technology advances in power beaming (lasers and millimeter or submillimeter microwaves), photovoltaics (multispectral cells with efficiencies up to 40%), low-cost launch vehicle concepts (electromagnetic and gas-gun launchers and both airbreathing and rocket-powered single-stage-to-orbit designs), and large-scale space structures called for reconsideration of the now-obsolete "reference designs" evaluated in the late 1970s. The symposium identified the use of lunar materials for orbiting power stations, constructing power stations on the Moon, and using lunar-surface helium-3 for Earth-based fusion powerplants as possible future options. Several power-beaming experiments using S-band microwaves (2.45 GHz) and lasers are being explored for the International Space Year.

C. Structures and Materials

A one-third-scale model of a large (10-m diameter) deployable antenna was built at Japan's Institute of Space and Astronautical Sciences. The antenna, which will be an element of the Very Long Baseline Interferometer scheduled for launch in 1995, consists of a flexible metallic mesh, a cable network which supports the mesh in a precise parabolic shape, and six radial masts which extend outward. This is the first space structure to use a pre-tensioned cable network. A partial full-scale model is to be completed by the end of 1991.

Japan also completed building the components of a 3.5-m deployable solid-surface antenna, to be used on ETS-VI which is scheduled for an H-2 launch in 1993. During launch the antenna's dish is stowed in three pieces, which are deployed into a single dish by springs when the spacecraft reaches orbit. Final assembly of the antenna will be accomplished by the end of the year.

During 1991 the United States National Aerospace Plane (NASP) program developed several new lightweight and high-temperature materials. Composites using graphite, polymers, and ceramic fibers can reduce the structural weight of spacecraft by up to 50%, and titanium-matrix composites were demonstrated in August to retain their strength at temperatures over 700 Celsius. NASP-derived carbon-carbon composites, descended from those used on the United States and Soviet shuttles, are expected to survive much longer duration trajectories at temperatures exceeding 1700 Celsius.

D. Space Debris

An Orbital Debris Program was established in the United States this year by NASA and the Department of Defense to improve modeling, monitoring, and data processing of debris 0.1 to 10 cm diameter in low Earth orbits. Japan's National Aerospace Laboratory is also modeling debris structure and collision processes on its supercomputer.

The 68-month flight of NASA's Long Duration Exposure Facility (LDEF) resulted in detection of over 15,000 meteoroid impacts from both natural and human sources, 5,000 of which were larger than 0.5 mm. Measurements included beta meteoroids, which are accelerated by solar radiation, and debris impacts on LDEF's trailing edge, implying the existence of debris in elliptic orbits. Results from LDEF are already being incorporated into the design of Space Station Freedom by the United States, Europe, Japan, and Canada.

Three spent rocket stages exploded between October 1990 and June 1991 -- one of them after 16 years in orbit -- releasing over 500 trackable pieces of debris into very long lifetime orbits and endangering, in particular, spacecraft in orbits between 1000 and 1700 km.

Ball Aerospace and Kaman Aerospace in the United States completed preliminary conceptual design of a Debris Collision Warning Sensor for possible use aboard space station

Freedom. It is a 1-m optical telescope that would eventually be paired with a high-power radar detector for final tracking of debris spotted by the telescope. It could be ready for test in the United States Shuttle by 1995.

E. Microgravity Research Facilities

The French space agency CNES has proposed development of a recoverable capsule able to carry 900-kg payloads into low Earth orbit for up to 3 weeks. The capsule, called Cariane, would be launched as an auxiliary payload on Ariane 5, and separated at the same time as the vehicle's first stage.

NASA selected three contractors to provide the six services needed for its Commercial Experiment Transporter (COMET) program: Space Industries, Space Services, and Westinghouse. First launch is scheduled for September 1992. Westinghouse also annouced availabilty of its Westar launch-and-retrieve experiment capsule service, scheduled for first launch in 1993. It can be used not only with the COMET launcher but also with other launch vehicles. The capsule carries up to 140 kg of payload and remains in orbit 30-100 days.

Novespace (France) completed microgravity experiments for ESA, CNES, and Japan's Ministry of International Trade and Industry aboard a French Defense Ministry Caravelle Zero G aircraft modified for microgravity research by CNES. The business volume generated by these test series allowed the firm to cut the price for a 3-day series, involving up to 120 parabolic flight maneuvers each providing about 25 seconds of microgravity for a 150-kg payload, to US$28,000.

On 8 May a Maxus sounding rocket launched from Sweden's Esrange facility in Kiruna reached only a quarter of its intended altitude (200 km vs 800 km, which would have provided 15 minutes of microgravity time). A joint effort of MBB (Germany) and the Swedish Space Corporation, Maxus is designed to carry 420 kg to 875 km. Its first payload was a group of ESA experiments on materials, biotechnology, and fluid mechanics.

The first flight of the United States Prospector sounding rocket, built by Orbital Science Corporation's Space Data Division for the Joust microgravity research program, failed on 18 June when it was destroyed after veering off course. It was the first failure of a Space Data rocket after 13 successful launches. Subsequent Space Data launches of two Zest rockets carrying military research payloads, were successful.

On 18 June Alenia Spazio (Italy), Deutsche Aerospace, and Matra Marconi Space (France) signed an agreement to operate ESA's 4,000-kg Eureca retrievable platform, scheduled for launch by the United States Shuttle in 1992. The agreement will take effect after the first flight. Eureca can remain in orbit for 6-9 months.

F. Microgravity Research

During the flight of the United States Shuttle Atlantis from 2 to 11 August three different techniques were used to grow large, high-quality protein crystals in the Bimda commercial payload. Aldolase was grown by materials dispersion, and crystals of urokinase were grown both by osmotic dewatering and by liquid-to-liquid and gradient diffusion.

PART TWO: PROGRESS OF SPACE RESEARCH 1990-1991

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

A. Research Activities

1. Meteorology and Climatology of the Lower Atmosphere and Oceans

(a) Earth Radiation Budget

The Earth Radiation Budget Experiment (ERBE), a three-satellite mission [Earth Radiation Budget Satellite (ERBS, launched 1984); NOAA-9, launched 1984; and NOAA-10, launched 1986], experienced failures of its last scanners in 1990. A 2-year merged data set of ERBS/NOAA-9 data has now been archived and represents a unique source of information on the diurnal and seasonal variations of the Earth's radiation budget. In addition to new information on the atmospheric greenhouse effect and its relation to surface temperatures and precipitable water amounts, the ERBE data set is providing new validation data for climate model simulations.

Since 1974, the National Oceanic and Atmospheric Administration (NOAA) has been providing nearly continuous coverage of the outgoing long wave radiation (OLR) flux and the planetary albedo from sensors on the polar-orbiting satellites. While current OLR products are derived from a single channel on the Advanced Very High Resolution Radiometer (AVHRR) in the thermal infrared portion of the spectrum, an OLR product derived from four channels on the High-Resolution Infrared Sounder instrument has been developed and is being implemented. Beginning in May 1988, the planetary albedo has been computed from a scene-independent linear combination of two channels on the AVHRR and corrected for reflected radiation.

The French-Soviet-German radiation budget radiometer ScaRaB, to alternate with ERBE, is now scheduled for a first flight in the fall 1993 on a Soviet Meteor satellite. Research groups are performing the first tests of the analysis algorithms.

A new and well-maintained surface network to measure various radiation properties at ground level, the Baseline Surface Radiation Network (BSRN), is now being established by the WCRP to support ground-truth controls of surface radiation budget quantities, which are derived from various satellite observations.

(b) International Satellite Cloud Climatology Project (ISCCP)

The World Climate Research Program's (WCRP) International Satellite Cloud Climatology Project, which began in 1983 to gather data from the global network of geostationary satellites and the NOAA polar orbiters, has now processed the observations into 5 years of cloud climatological statistics. The ISCCP cloud data sets, which are archived at the ISCCP Central Archive at NOAA, include information on cloud amounts (total and according to cloud type), temperatures, pressures, and optical thicknesses, as well as additional data on surface and atmospheric properties. International commitments are being sought to extend the project through June 1995. Improved algorithms are being developed for polar region cloudiness.

(c) Global Energy and Water Cycle Experiment (GEWEX)

The WCRP's plans for a very comprehensive GEWEX are now firm. The overall objective of GEWEX is to gain an operative knowledge of the global energy and water budget by means of observational and modeling studies. This experiment requires intensive spaceborne measurements in the microwave spectrum to determine precipitation over all portions of the Earth. First, regional projects, such as the GEWEX Continental-scale International Project (GCIP), are being developed to permit various required systems tests.

(d) Gulf War Environmental Effects

NASA researchers participated in the global research effort to study and understand the global consequences of the oil well fires which resulted during the war in the Persian Gulf. In addition, NASA researchers using aircraft and satellite data began studying the global effects of the eruption of the Mt. Pinatubo volcano.

The NOAA OLR and albedo observations have been extremely useful in monitoring the climatic effects of the burning Kuwaiti oil in the Persian Gulf region. Large decreases in the cloudless albedo were observed over normally bright desert sand, the day after the fires were set. These decreases persisted for months as the fires were slowly extinguished causing local surface temperatures to dip below normal values. The Mt. Pinatubo volcano was also monitored and the very low values in the OLR of the ash clouds were noted.

2. Dynamics, Geochemistry, and Climatology of the Middle Atmosphere

(a) Overview of Recent Research Activities

The structure and composition of the middle atmosphere is determined by the complex interplay of dynamics, chemistry, and radiation. Satellites, rockets, and other remote sensing experiments have provided us with a wealth of new information in recent years about the middle atmosphere. At the same time, the information gathered reveals new areas of complexity. For instance, the recent satellite observations of the amount of SO_2 and other gases emitted through the eruption of the Mt. Pinatubo volcano in the stratosphere raises new questions concerning the composition and radiative balance of this atmospheric region. Notably, the SO_2 amount from the Pinatubo was observed by TOMS instrument on the Nimbus 7 satellite to be more than twice as large as the total SO_2 emitted by El Chichon. Since such volcanic episodes are supposed to cause cooling of the Earth's surface due to sulphate aerosols, which reflect back the sunlight, a thorough study of their large scale transport and radiative effects is being undertaken.

Recent revised analysis of satellite observations of atmospheric ozone have confirmed the decrease over large regions of the world. Similarly, series of measurements made since 1979 of the stratospheric/mesospheric temperatures in France show a decrease in temperature of 5 K between 55-75 km altitude during the last 12 years. This decrease is twice that predicted by models to occur in the middle atmosphere owing to the increase of greenhouse gases (e.g., CO_2, CH4, N_2O, CFCs), emitted in the atmosphere due to fossil fuel burning.

Perhaps the greatest challenge for the next few years will be to determine the detailed changes in the vertical profiles of all the greenhouse gases and the resulting temperature/dynamics changes in the middle atmosphere and their possible effects on the lower atmosphere.

The launch of Upper Atmosphere Research (UARS) (September 1991) opens a new era of middle atmosphere research, although the strengthening of the worldwide network of rocket, balloon, and ground-based observations to support and validate satellite observations remains an absolute necessity. It is encouraging to report that a fairly large scale program of rocket and balloon- borne observations of the middle atmosphere was undertaken in India under the Indo-Soviet collaborative agreement for participation in the international program DYANA.

(b) Ozone Observations, Research, and Assessments

NASA continued its broad program aimed at improved understanding of the nature of ozone depletion and the ozone layer. A Solar Backscatter Ultraviolet (SBUV) instrument flew on the Shuttle in October 1990 and August 1991 to gather on-orbit data needed to calibrate direct ozone measurements by TOMS and other NASA and NOAA satellite instruments. NASA researchers confirmed that the ozone hole over Antarctica was as severe in 1990 as in previous years. In addition, researchers at NASA's Goddard Space Flight Center (GSFC) reprocessed nearly 12 years of measurements of total column ozone from the TOMS instrument aboard the Nimbus-7 satellite which indicated that the ozone depletion over the Northern mid-latitudes--including the United States--was approximately twice as severe as originally reported on the basis of uncorrected data. NASA scientists will also be making substantial contributions in updating the Scientific Assessment of Stratospheric Ozone prepared under the auspices of the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). All three assessments will be completed and distributed to the participating governments by January 1992, six months in advance of the review of the Montreal Protocol on Substances that Deplete the Ozone Layer.

(c) Airborne Arctic Stratospheric Expedition II

The 1991-1992 Airborne Arctic Stratospheric Expedition (AASE II) involves an extended aircraft campaign designed to investigate the Arctic polar stratosphere over the complete annual lifetime of the Northern hemisphere polar vortex. This is a period in early winter when polar stratospheric clouds are most likely to form. The AASE II consists of five or six 2-week data-gathering phases taking place between October 1991 and April 1992. It employs the NASA

ER-2 research aircraft and the NASA DC-8 "flying laboratory." AASE II is being staged from Fairbanks, Alaska during October 1991, with the base of operations shifting to Bangor, Maine for the remainder of the mission (ending April 1992).

Various satellite data can now be converted into information on polar sea-ice coverage, ages, and even thickness. Furthermore, rough estimates of the surface radiation budget are possible. These SRB values enable more accurate modeling of the sea-ice thickness. An Arctic Climate Systems Study (ACSYS) has now been defined as one of the WCRP subprograms.

3. Geology and Productivity of the Land Surface and the Oceans

(a) Geology

Satellite imagery of high resolution optical sensors, such as Landsat Thematic Mapper and SPOT High Resolution Visible (HRV) imager, are being widely applied for lithological mapping and detection of structural features. In combination with field data, this information is used for the compilation of geological maps as well as for guidance of field exploration of hydrocarbon and mineral resources. A 2-year project on the geology of the Central Andes Mountains, as a basis for mineral prospection using Landsat TM data, has been initiated in 1990 by the Geological Surveys of Bolivia, Chile, and Peru and is supported by the United States Geological Survey and the Inter-American Development Bank. In Israel, a ground receiving station for SPOT commenced operation recently. Among other applications, SPOT data from this station, as well as Landsat images, are applied for lithological mapping and investigations of mineral resources.

Experiments with airborne synthetic aperture radar (SAR) were carried out in various countries in order to develop methods for mapping of structural and geomorphological features and to prepare for future spaceborne SAR programs such as the European ERS-1 SAR and the Shuttle Imaging Radar-C/X-SAR experiment. Among the systems used for this task was the 3-frequency (P-, L-, C-band) polarimetric AIRSAR of NASA/JPL and the dual frequency (C/X-band) airborne SAR of the German Aerospace Research Establishment.

Satellite image data show considerable potential for mapping and evaluation of hazard zones with risks of mass movements, earthquakes, and volcanic eruptions. The risks are especially high in the tectonically active zones of the world. The application of high resolution satellite imagery for hazard mapping has been reported for the American earthquake belt, the southwestern United States, the Arequipa volcano area in Peru, and the Equatorial Andes. The Environmental Monitoring Systems of Tibet, a project on the assessment of mountain hazards and on environmental degradation related to erosion and human activities, has been initiated in 1991 in cooperation between the Tibetan authorities and the Austrian Academy of Sciences. As contribution to the "Major Risk Decade" (1990-2000) activities on the development of improved methods for mapping of geological instability risks, using satellite data in combination with other sources, are going on in various countries.

Research organizations from Japan and other countries are using satellite and airborne remote sensing data for observation of the volcanic activities of Mt. Pinatubo and Mt. Unzen. The activities include SAR and thermal IR observations of the lava flows and eruption monitoring by means of GMS-4 and NOAA-10 imagery.

Precise positional measurements by means of the satellite-based Global Positioning System (GPS) are an important basis for studies of lithospheric movements. A major ongoing geophysical project is the Europrobe project which includes seismic experiments and measurements of the lithospheric movement on the European continent from the Atlantic to the Urals.

(b) Land Productivity and Environmental Monitoring

Projects on land use mapping and land cover statistics based on high-resolution optical satellite imagery are going on in many countries. An extensive pilot project on the application of remote sensing to agricultural statistics is carried out by the Commission of the European Communities (CEC). Within this project, regional crop inventories are established from SPOT and Landsat data, vegetation conditions and yield indicators are derived from various data sources including NOAA AVHRR images, and yield prediction models are set up by combining agrometeorological and satellite-derived data. In cooperative projects between the CEC and local authorities, similar techniques are presently also being tested for application to crop yield monitoring in tropical and subtropical zones of Africa.

Earth observation from space has been recognized as the only efficient means of providing continuous and consistent global information on the extent and conditions of tropical and boreal forests. A major program to monitor tropical deforestation is the project Tropical Ecosystem Environment observation by Satellites (TREES), which has been recently initiated by ESA and CEC. Within this project, techniques are presently studied for deriving forest properties from satellite data, using optical sensors (NOAA AVHRR, Landsat TM, SPOT HRV) as well as SAR (ERS- 1). These methods will be the basis for a global tropical forest inventory and for long-term monitoring of changes in forest cover. Brazil's Institute for Space Research carried out an intensive research program to evaluate the deforestation rates of the Brazilian Amazon region during the last few years, based on large quantities of Landsat TM images.

The Landsat Thematic Mapper has also been found a valuable information source for the assessment of vegetation damage due to air pollution and overgrazing at high latitudes, as reported from a Norwegian- Soviet cooperative project on environmental problems in Northern Scandinavia.

Images of Earth observation satellites are used in many countries for inventories and management of water resources and for monitoring of water quality. Projects on the development of water resources and on irrigation management using satellite based remote sensing are carried out for the River Nile in Egypt and for the delta of the River Niger. Significant contributions to the conservation of fresh water in Southern California are expected from Landsat derived maps of irrigated areas. High-resolution optical satellite imagery is applied in various countries for monitoring of wetland areas and aquatic vegetation, aiming at the protection of ecologically valuable areas, which are increasingly threatened by agricultural and rural development. Among the areas studied are the Danube river in Bulgaria and major wetlands in Florida.

In June/July 1991, the Multi-Aircraft Campaign (MAC) Europe was carried out in cooperation between NASA, ESA, CEC, and various European research institutes. Imaging spectrometers, multispectral scanners, and synthetic aperture radars were flown on several aircraft over about 30 different test sites. The campaign provides a valuable basis for the development of data analysis techniques for advanced sensors and for the preparation of future spaceborne systems in the fields of agriculture, forestry, soil science, hydrology, volcanic geology, and coastal oceanography.

(c) Ocean Productivity and Pollution Monitoring

Landsat Thematic Mapper and SPOT images are used to quantify and map the distribution of live aerial biomass of tidal marshes along the East coast of the United States. Comparisons of these biomass estimates with ground-gathered radiance and harvest data at various test sites showed good agreement. Detailed analysis of the multi-annual data set of the Coastal Zone Color Scanner (CZCS), which operated aboard the Nimbus-7 satellite from 1978 to 1986, is going on at various institutes, yielding maps of chlorophyll-like pigment concentrations. Of particular interest for studies of ocean productivity and circulation of water masses are combinations of CZCS data with sea surface temperatures. Detailed studies have been carried out for coastal upwelling areas such as the Northwest African coastal zone and the US West coast. Investigations of a major red tide event on the West coast of Canada in August/September 1990 demonstrated the value of NOAA AVHRR images for studies of algal blooms at high cell densities. Landsat TM and SPOT HRV images are being applied for estimation of chlorophyll and sediment concentrations in various coastal areas. High resolution satellite imagery is also a valuable source for off-shore mapping and has been particularly useful in complex coastal areas such as the Philippines Archipelago.

Various airborne experiments on mapping the extent and properties of oil slicks have been carried out based on imaging radars and multifrequency microwave radiometers as well as on optical sensors. One of the larger experiments on microwave backscatter from the sea surface, including effects of sea slicks, has been the German/American multi-institute SAXON-FNP experiment, performed in November 1990 in the area of the German research platform North Sea, with participation of six aircraft equipped with active and passive microwave sensors. In various coastal areas, Landsat and SPOT images are used to detect the distribution of spilled oil, but the temporal repetition rate and weather dependence of the sensors limits the operational use. Significant advancements for this task are expected from spaceborne SAR.

The Sea-Viewing Wide Field Sensor (SeaWIFS) is an instrument that will acquire high quality global ocean color measurements. This information is important to understanding biogeochemical processes, climate change, and oceanography. Planned as a precursor to the

Earth Observing System, SeaWIFS will serve as a follow-on to the Coastal Zone Color Scanner which flew aboard Nimbus-7 in 1978. SeaWIFS is being developed commercially, with a contract in place for the provision of data to NASA. The owner of the satellite will build and operate the instrument and retain rights to sell the data to other clients. SeaWIFS data may be of particular commercial interest because they can be used to pinpoint the locations of large concentrations of fish which feed on observable phytoplankton. Development of SeaWIFS began in May 1991. Launch is expected in the summer of 1993.

B. Application Activities

1. Atmospheric Temperature and Moisture Soundings

The year 1991 marks the 12th year of operational atmospheric sounding production from NOAA's polar-orbiting satellite system. These soundings are used by both the military and civilian meteorological communities as input to numerical weather forecast models. Numerous requests for sounding data and science software/techniques, from both military and civilian researchers were honored. Preparations are under way for the development of the next generation operational sounding system which will implement new science needed for the NOAA-K satellite instrumentation (including an advanced microwave sounder). As with the NOAA satellite series, the data from the Special Sensor Microwave/Temperature (SSM/T) instrument on board the Defense Meteorological Satellite Program (DMSP) polar orbiter, were operationally processed into soundings. The use of data from the Special Sensor Microwave/Imager (SSM/I), also on board the DMSP spacecraft, combined with the SSM/T data is being explored as an option for improving the soundings. Upgrading of the DMSP sounding science software to be consistent with that developed for NOAA satellites is in progress. Products from the DMSP satellites are operationally archived and distributed under the Shared Processing agreement between NOAA and the Department of Defense (DOD)--the Navy and Air Force. Development of the sounding product processing system, of the next generation geostationary satellite series (GOES-I/M), is currently under way. This system will provide temperature and moisture sounding information for the NOAA National Meteorological Center Regional Forecast Models, and images of atmospheric stability and moisture to the NOAA National Severe Storms Forecast Center and the NOAA National Hurricane Center.

2. VAS Applications

GOES-7 Visible-and-Infrared-Spin-Scan-Radiometer (VAS) data continue to be used operationally by all of the NOAA National Weather Service National Centers--the National Meteorological Center (NMC), the National Severe Storms Forecast Center (NSSFC), and the National Hurricane Center (NHC). Imagery, VAS-CO_2 slicing techniques, and moisture analyses were utilized by NMC in both their global forecast models and national forecasting programs. The NSSFC is using the GOES-7 water vapor channel to fine tune locations and timing of outlooks and watch areas for severe weather. Imagery and a special VAS-derived Deep Layer Mean (steering current) analysis were used by the NHC in the monitoring and forecasting of hurricanes (including Atlantic, Gulf of Mexico, and Caribbean Basin storms) which affect the United States.

3. GOES-Tap

GOES-Tap, a program enabling users to acquire high-quality satellite imagery over telephone data circuits, continued to expand. Currently, there are approximately 350 primary users and over 500 secondary users of GOES-Tap data. These users are primarily the National Weather Service (NWS) field forecast offices, and also the Department of Transportation's Federal Aviation Administration, other civilian agencies (both State and Federal), the Department of Defense, private companies, universities, and the media. A significant number of high schools have also started receiving NOAA satellite images via GOES-Tap. GOES-Tap data consist of visible and infrared facsimile images from the GOES and NOAA satellites, Geostationary Meteorological Satellite (Japanese), and Meteosat (European) spacecraft. During 1991, NOAA continued to expand its suite of available NOAA polar satellite products accessible to the NWS field offices. In addition, high-resolution polar imagery is now gridded with geo-political boundaries and contains a machine- readable identification code.

4. Satellite-Based Fire Alarms

The National Geophysical Data Center (NGDC) of the NOAA National Environmental Satellite, Data, and Information Service (NESDIS), in partnership with the Department of the Interior (DOI) National Park Service and Bureau of Land Management, has contracted with NASA to develop a prototype operational system for using the NOAA Advanced Very High Resolution Radiometer (AVHRR) for automated early detection of wildfires.

Wildfires cause great loss of forests. Forest managers must decide which fires are constructive and which are destructive to overall forest development. The techniques developed under this program should assist managers in making such decisions. Interest has extended to international organizations such as the United Nations Food and Agriculture Organization (FAO), and to other nations such as Italy.

NGDC's involvement will be reduced in October 1991. However, NGDC will continue to help the agencies in DOI evaluate possible follow-up to the project.

5. Volcano Hazards Support

GOES-7 and NOAA polar data continue to be utilized to define the horizontal and vertical extent of ash clouds, as well as their direction and speed of movement.

Although a few minor eruptions occurred during late 1990 and 1991 from the Redoubt Volcano in Alaska, the Mount Pinatubo eruption in the Philippines (volcano and ash were not in United States controlled air space) emphasized the need for an expanded role of the United States to help detect, track, and forecast ash clouds. The First International Symposium, co-sponsored by NOAA, on Volcanic Ash and Aviation Safety was held in Seattle, WA, during July 1991.

6. CoastWatch

Operational support of CoastWatch activities and products began in 1989. At present, there are three regional CoastWatch sites providing operational support, these are located at NOAA facilities in Beaufort, North Carolina; Narragansett, Rhode Island; and Ann Arbor, Michigan. In 1991, development of a CoastWatch site in Florida to serve the greater Caribbean was initiated.

NOAA's inter-agency Ocean Products Center provides the regional sites with operational products such as high resolution AVHRR satellite-derived sea surface temperature (SST) imagery, meteorological fields, and oceanographic information in near real time via the electronic delivery system known as the NOAA Ocean Communications Network.

A new satellite mapping capability called IMGMAP was operationally implemented in mid-1991. As compared to an older, non-operational routine, IMGMAP provides improved coastlines, better land/sea tags, more accurate satellite derived SST's, and most notably, the ability to automatically remap high-resolution satellite images for each coastal State of the United States.

An inexpensive, personal computer-based work station has been developed to interactively display and analyze satellite and other environmental information which supports Federal, State, and local decision-makers and researchers responsible for managing coastal living marine resources and ecosystems.

Data management is provided through the NOAA CoastWatch Archive and Access System, an optical mass storage system on-line at the National Oceanographic Data Center for near real-time capture and retrospective availability and distribution of CoastWatch data and products. CoastWatch-funded research efforts include Chesapeake Bay, Albemarle and Pamlico Sounds water reflectance/turbidity studies, phytoplankton "red tide" blooms, El Nino monitoring, coastal circulation analysis, and development of an ocean color index.

As part of the CoastWatch program, the Change Analysis Program (C-CAP) is developing a comprehensive, nationally standardized, information system for land cover and habitat change in the coastal region of the United States. Satellite imagery, aerial photography and surface level data will be interpreted, classified, analyzed, and integrated within a geographic information system. The program will delineate coastal wetland habitats and adjacent uplands and monitor changes in these habitats on a cycle of 1 to 5 years.

Program products will strengthen conceptual and predictive models and improve coastal resource policy planning and analysis. Operational protocols are being developed through a series of interagency workshops and meetings focusing on: coastal emergent wetlands and adjacent uplands, submerged aquatic vegetation, and user products.

7. Strategic Environmental Assessment Program

This program managed by the Office of Ocean Resources Conservation and Assessment (ORCA) of NOAA's National Ocean Service (NOS) uses NOAA and NASA satellite data to produce analyses which describe the physical and biological conditions within estuaries, adjacent coastal waters, and the continental shelf. Satellite imagery data are acquired and analyzed to determine: the location, movement, and spatial extent of estuarine plumes and shelf/slope fronts; the interactions and exchanges of water between estuaries and coastal oceans; and the distribution and concentration of primary productivity zones. The analyses produced by the Strategic Environmental Assessment Program are used by coastal managers to help in the continuing monitoring and assessment of the environmental context within which living marine resources must survive.

8. Precipitation

Improvements to the forecasting of heavy rainfall continue. Imagery from the GOES satellite is proving to be an excellent tool for quickly locating: mid-level systems associated with upward vertical motion; areas of relatively deep moisture; and unstable air masses. All of these are ingredients for producing thunderstorms, especially those associated with heavy rainfall. The presence of low-level moisture can increase the rainfall efficiency from thunderstorms. When polar or subtropical moisture approaches or intersects tropical moisture, thunderstorms can develop, producing flash floods. Techniques employing microwave satellite data for monitoring global precipitation are currently quasi-operational. Automated techniques to estimate rainfall from infrared satellite data are also being developed to improve the forecasting of flash floods and to lead to better water management.

The Global Precipitation Climatology Project (GPCP) of WCRP is continuing to collect precipitation information from satellite and ground-based measurements. The satellite precipitation estimates are based mainly on infrared brightness temperature measurements from the global network of geostationary satellites. The data are archived at the Global Precipitation Data Center (GPDC) in Offenbach, Germany.

9. Aerosol Optical Thickness

Although experimental production of this NOAA product (over global oceans) began in July 1987, operational production began in January 1990 and continues. A cooperative project with the Navy in the summer of 1990 resulted in an airdrop of drifting buoys in the Eastern Atlantic off the coast of Northwest Africa, an area where Saharan dust is prevalent. Close (time/location) matchups of the buoy and satellite data have enabled development of an aerosol correction algorithm for AVHRR-based daytime sea surface temperature retrievals.

The eruption of Mount Pinatubo in the Philippines in June 1991 and the subsequent creation of a tropical belt of volcanic aerosol in the high stratosphere has been readily monitored by means of the weekly-composite aerosol product. Five weeks after the eruption, the entire equatorial region, from 20 degrees South latitude to 25 degrees North latitude, was affected by the stratospheric aerosol particle layer generated by the eruption. This increase in reflected solar radiation could cause the Earth's surface temperature to decrease by up to 0.5 degrees Celsius over the next few years.

10. The Climate and Global Change Program

NOAA is pursuing its program of producing and maintaining the continuity of climate products from operational satellites. Examples of some of these products include the following:

- Since 1969, global atmospheric soundings of temperature and moisture. Significant improvements in these soundings occurred in 1979 with the introduction of the Television-and-Infrared-Operational-Satellite (TIROS) Operational Vertical Sounder (TOVS).

- Since 1970, global sea surface temperature. High quality observations began in 1981 with the launch of a 5-channel Advanced Very High Resolution Radiometer (AVHRR).

- Since 1966, maps of snow cover showing, for example, that the summer snow cover over the Northern hemisphere this past summer was the lowest of the entire 25-year satellite record.

- Since 1972, maps of sea-ice cover on the oceans.

- Since 1982, weekly global maps of vegetation index, a measure of the vigor and density of green vegetation.

- Since 1974, quantitative estimates of the global distribution of Earth's albedo and emitted long-wave radiation, the two major components of Earth's radiation budget.

- Since 1985, the global distribution of the total amount and vertical profile of atmospheric ozone.

In addition, NOAA has undertaken new activities to improve and expand its suite of high quality climate data to meet the goals of the United States Climate and Global Change Program. These include:

- OPSAT '90 Conference-- A conference on Operational Satellites: Sentinels for Monitoring Climate and Global Change. This conference examined the role of operational satellites in observing global climate systems and helped define the climate variables obtainable from current and future satellites.

- Calibration Workshop-- A Workshop on Radiometric Calibration of Satellite Sensors of Reflected Solar Radiation was hosted by NOAA. The calibration of the short-wave sensors is critical if the data are to be used for climate studies. This workshop addressed the problem of obtaining the most accurate calibration of the visible and near infrared sensors on the operational spacecraft which currently have no onboard calibration.

- Pathfinder Data-- NOAA and NASA have initiated a joint program to generate and make available to the global change research community "research/climate" quality data sets. Three NOAA operational satellite data sets have been identified as Pathfinder data sets under this activity: the five-channel Advanced Very High Resolution Radiometer (AVHRR) data, since 1981; the TIROS Operational Vertical Sounder (TOVS) data, since 1979; and the GOES data, since 1978.

- Operational Measurements Project-- In order to provide continuous data and information products from operational satellite and *in situ* observations for the United States Global Research Program, NOAA has initiated a project on Operational Measurements as part of its Climate and Global Change Program. The Operational Measurements project will improve NOAA's ability to observe the physical climate system. Because of its global observing capabilities, the emphasis of this project will be the operational satellite observing system. New and improved climate information products will be made available for studying the atmosphere, oceans, land surface, and cryosphere.

11. Ozone

Analysis of the currently archived total ozone data derived from measurements by the Solar Backscatter Ultraviolet Spectrometer/2 (SBUV/2) instruments on the NOAA-9 and -11 satellites have been merged along with data from the SBUV on the NASA Nimbus-7 satellite. The combined data set was then harmonized with data from the global Dobson spectrophotometer network and analyzed in order to evaluate trends over the resultant 11-year data record. While the analysis is preliminary, the trends showed a decrease of global total ozone amount of about 3 percent per decade. This was in general agreement with trends derived from other satellite data.

12. Global Vegetation Index

The experimental Global Vegetation Index (GVI) product of NOAA provided a one-per-week view of Earth's vegetation since May 1982. The GVI is derived from daily data acquired by the AVHRR onboard the NOAA polar-orbiting series of satellites. The quality and use of the normalized difference vegetation index (NDVI) data in Global Circulation Models as direct indicators of year-to-year and regional variations in climactic conditions have been further improved as a result of research efforts.

13. Snow Cover Observations

As of November 1990, NOAA began its twenty-fifth year of producing the NOAA satellite-based Northern Hemisphere Weekly Snow and Ice Cover Chart. This is the longest satellite-based climate record. Work continues to upgrade this product by evaluating microwave data from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) sensor as well as the daily United States Air Force global snow cover product. The National Weather Service (NWS) is studying the use of snow cover data for improving their forecast models.

14. Generic Cloud Algorithms

A multichannel algorithm for cloud detection is under development. The objectives are to provide a method for detecting clear pixels for remote sensing of surface parameters and a means of estimating cloud amount and other cloud properties useful for diagnosis and initialization of climate and weather prediction models.

Increasing concern in the scientific community regarding global cloud census has led to an improvement in the estimates derived from polar and geostationary satellites using radiances in the carbon dioxide bands in concert with atmospheric window measurements. A two- year global climatology has been prepared as a pilot program. This research has also spawned an operational product which will be used by NWS to augment the Automated Surface Observing System of the Modernized Weather Service.

15. Sea Surface Temperature Measurements

Sea surface temperature (SST) measurements have been provided by the National Environmental Satellite, Data, and Information Service (NESDIS) in real-time on a global basis since 1981. These SSTs are derived from 4 km resolution, multi-channel (visible, reflective, and thermal-infrared), and digital data from the AVHRR instrument. The non-linear model implemented in March 1990 to better correct for atmospheric attenuation by water vapor has worked well, but it was replaced in April 1991 by a simpler and improved non-linear version. The eruption of Mt. Pinatubo in the Philippines in June 1991 has had a significant effect on AVHRR-based SSTs in the tropics. The impact is stronger but is much like that experienced with the apparently weaker El Chichon eruption in 1982, viz. a severe loss in day-time SST retrievals and a degradation in accuracy of the night-time ones. Methods of correcting for these effects, which were developed from data during the El Chichon episode, are under investigation.

16. Mesoscale and Severe Storm Research

NOAA researchers continue to develop satellite-based products to improve forecasting of severe and tornadic thunderstorms. Work this year has focused on using interactive computer systems to quickly and accurately analyze rapid changes in the thunderstorm environment. Recent research is pointing to the interaction of the thunderstorm with its environmental flow fields for defining the crucial difference between storms with beneficial rains and those with destructive ones. NESDIS has developed products to look at these flow fields in real-time and allow the forecaster to look at satellite imagery in a storm-relative reference frame.

17. Tropical Cyclone Research

NOAA research uses observational data from satellites, aircraft, and conventional weather data to improve the understanding of tropical cyclones. Tropical cyclones occurring in the Atlantic, Eastern Pacific, Western Pacific, and Australian regions have been extensively analyzed using digital multi-spectral satellite images. The genesis, intensity, and motion of tropical cyclones are the primary topics being studied with these multi-spectral data sets. Objective techniques have been made available to operational tropical cyclone forecast centers at the National Hurricane Center, Miami, Florida, the Joint Typhoon Warning Center, Guam, and NESDIS, Washington, D.C.

18. Hurricane Operations

GOES continues to carry the major load in positioning and estimating the strength of tropical cyclones outside of the aircraft reconnaissance areas for the Western Atlantic, Caribbean Sea, Gulf of Mexico, and the Eastern Pacific. Meteosat was used to supplement GOES in the far eastern Atlantic Ocean. As a supplement to GOES-7 imagery, NOAA's National Hurricane Center (NHC) continues to ingest imagery from a Meteosat spacecraft located at 0 degrees West longitude. Additionally, NHC has begun to ingest imagery from a second Meteosat spacecraft, recently relocated to 50 degrees West longitude. The satellite provides continuous monitoring for early detection of changes while the aircraft provides precise spot observations.

In the Eastern hemisphere (that is, the Western Pacific and Indian oceans), the NOAA polar orbiters provide the essential coverage for tropical cyclone monitoring. The NOAA data are used to provide position and intensity estimates for the US Joint Typhoon Warning Center in Guam and for foreign meteorological services, as part of the World Weather Watch program of the World Meteorological Organizations (WMO).

NHC is using the Special Sensor Microwave/Imager (SSM/I) wind and rain-rate algorithm to improve products. The SSM/I algorithm has been used to make estimates of wind radii for Marine Advisories as well as to produce rain estimates (when the tropical cyclones are expected to make landfall) for Public Advisories.

19. Aviation Applications

A color image display has been developed that shows the approximate thickness of fog and stratus clouds. It is based on the temperature difference of two GOES infrared channels. Such estimates are useful in determining the time required for fog to clear an airport terminal area. Preliminary data show the estimates to be accurate to about 100 meters. An effort is under way to determine the Northern hemispheric distribution of Clear Air Turbulence (CAT) based on monthly, seasonal, and annual averages of an index calculated from forecast winds aloft. Preliminary results have made it possible to identify regions where CAT is relatively common. These compare favorably with pilot reports and the observation of turbulence signatures in satellite imagery.

Additionally, work is nearly completed on developing a new procedure for classifying mid-latitude winter cyclones in the Atlantic Ocean. Preliminary results show significant improvement over existing techniques for estimating the central pressure of full-latitude storm systems. An expanded study addressing North Pacific storms is planned for 1991-92.

20. Joint Global Ocean Flux Study

NOAA's National Ocean Service (NOS) is providing satellite image data, ship and buoy reports, and numerical forecast products to support this critical element of the Climate and Global Change Program. These data are communicated in real-time to the Joint Global Ocean Flux Study (JGOFS) Time Series Stations at Bermuda and Hawaii and are used by JGOFS scientists to direct data collection activities of participating research vessels, and to establish a surface climatology for the region around the monitoring station. The measurements collected by JGOFS will assist in the determination of differences between daily, seasonal, annual, and decadal changes in the net flux of planetary carbon, one of the important indicators of statistically significant changes in global climate.

21. GEOSAT

During the 5-year interval 1985-90, the United States Navy altimeter satellite "GEOSAT" has provided nearly continuous measurements of global sea level, wind speed, and sea state. Under agreement with the United States Navy, the NOAA GEOSAT project prepares and distributes raw data and products from this mission. Several hundred scientists in more than 50 institutions and countries receive geophysical data records on a regular basis.

Though the GEOSAT satellite failed in January 1990, putting an end to a long-standing flow of altimetric data, the interest in geophysical applications of the data continued to grow steadily. Launched in March 1985, GEOSAT substantially exceeded its expected 3-year life span. In 1991, two additional GEOSAT ocean data sets prepared by the NOAA National Ocean Service were released to the National Oceanographic Data Center (NODC) for worldwide dissemination to scientists. The GEOSAT Geodetic Mission Data for the Southern Ocean, extending from April 1, 1985, to September 30, 1986, consists of GEOSAT altimeter data acquired between 60 degrees and 72 degrees South latitude encircling Antarctica. Although altimeter data from the Geodetic Mission North of the Southern Ocean remain classified, a set of GEOSAT Crossover Difference Data from the Geodetic Mission was also released. These data include not only the initial 18-month Geodetic Mission, but also the first year of the subsequent Exact Repeat Mission enabling computation of continuous, 2.5-year sea level time series spanning the two GEOSAT missions. The NESDIS National Geophysical Data Center continues, along with the NESDIS National Oceanographic Data Center, to provide the community of users with these publicly available GEOSAT data and selected derived data.

The GEOSAT project is a key element of the NOAA Climate and Global Change Program, in particular, the NOS sea level portion. Satellite altimetry is the only way to obtain global and detailed determinations of sea level variations such as those associated with El Nino. In addition to providing data for geophysical and oceanographic research, the GEOSAT mission has enabled the first operational monitoring of sea level over entire ocean basins. At present, NOAA publishes sea level maps of both the Pacific and Indian Oceans in near-real time.

The GEOSAT altimeter is also being used to enhance models of the geoid and the gravity field of Earth's oceans. This information is fundamental to improving our understanding of numerous geophysical processes.

22. NOAA/NOS GEOSAT Altimeter Program

Since 1986 the National Ocean Service (NOS) has prepared GEOSAT altimeter data sets for distribution to the international scientific community. Although the satellite failed in early 1990, the 5-year United States Navy GEOSAT mission was the most successful oceanographic mission of its kind. Approximately 500,000 observations of sea level, wind speed, and wave height were collected each day over the global oceans. These data have been used at NOS to study sea level variations in the tropical oceans as they relate to global weather and climate.

During the past year a new GEOSAT data set has been prepared by NOS for distribution by the NODC to the oceanographic community. The geophysical data records (GDRs) have been upgraded by incorporating a more accurate satellite orbit and improved corrections for water vapor, tides, dry troposphere, and geoid. These new GDRs will be distributed on seven CD-ROMs (as opposed to the 36 9-track tapes). NOS is also actively supporting the next satellite altimeter, the European Space Agency Remote Sensing Satellite (ERS-1). NOS will assist in areas of calibration and verification and will use the fast delivery altimeter data to perform monthly monitoring of tropical sea level, as was done during the GEOSAT mission. ERS-1 was launched in July 1991.

The GEOSAT altimeter data are also being used to enhance models of the geoid and the gravity field of Earth's oceans. This information is fundamental to improving our understanding of numerous geophysical processes.

C. Operational Space Programs

1. Geostationary Environmental Satellites

(a) Europe

Meteosat-4 continues to operate as the primary satellite. Meteosat-5 was successfully launched in February 1991 and is in a stand-by mode. Plans are being formulated to loan Meteosat-3 to the United States to bridge a potential gap in coverage between GOES-7 and

GOES-I, which is currently planned for launch in 1993. The Meteosats carry a 3-channel radiometer providing observations in the visible window, an infrared water vapor band, and an infrared window.

(b) United States

Two GOES spacecraft are usually in service. Their combined views provide coverage that extends westward from near Africa to beyond Hawaii. In the mid-1980s, a launch failure destroyed a GOES satellite; thus, in 1989 when the GOES spacecraft failed in orbit (after providing long service) there was no spare to replace it. Since that time, a single satellite, GOES 7, has been performing double duty. It is positioned at 108 degrees West longitude to better observe storms in winter and moved to 98 degrees West longitude in summer to improve coverage of Atlantic hurricane regions.

A new series of five GOES satellites, designated GOES-I, -J, -K, -L, and -M respectively, is in development. Their construction was continued by the Space Systems Division of the Loral Corporation, which purchased the Ford Aerospace and Communications Corporation, the original contractor. Work on the first two spacecraft of the series included instrument fabrication and testing.

The GOES-I/M development program has experienced significant technical problems, schedule delays, and cost increases. Launch of the first spacecraft, GOES-I, cannot occur before mid-1993. GOES-7 is expected to continue in service through 1993. NOAA has asked for backup support from its European and Japanese space partners in the Coordination Group for Meteorological Satellites (CGMS), because catastrophic failure of the sole operating GOES-7 satellite would jeopardize the detection and tracking of hurricanes and other severe storms. In the past, NOAA has loaned or offered its GOES satellites to other CGMS members for emergency backup.

The NESDIS unit at the Cooperative Institute for Meteorological Satellite Studies at Madison, WI, developed a system for evaluating the effect on products caused by problems associated with the forthcoming GOES-I imager and sounder. The system was used extensively in making decisions regarding changes in specifications.

(c) Japan

The GMS-4 remains the operational Japanese geostationary spacecraft. GMS-5 is scheduled for a 1995 launch. The GMS spacecraft carry radiometers with two channels, one in the visible window and one in the infrared window.

(d) India

India's Insat-2 remains operational. Insat carries a 2-channel radiometer, with one channel in the visible window and the other in the infrared window.

2. Polar-orbiting Environmental Satellites

(a) China

China's second experimental polar-orbiting meteorological satellite Feng Yun-1B (FY-1B), successfully launched in September 1990, experienced tumbling problems in the spring of 1991 and is currently not operational. The FY-1B carried two 5-channel AVHRR-type instruments.

(b) France

SPOT 2 is the currently operational French Earth-resources type satellite.

SPOT 3 is scheduled for launch in 1993. Instrumentation consists of a 4-channel radiometer at visible and near-infrared wavelengths.

(c) Soviet Union

Meteor 3-5, launched in August 1991, is the current operational Soviet polar meteorological satellite. This satellite also carries a United States Total Ozone Mapping Spectrometer (TOMS). The ScaRaB radiometer, a joint French-Soviet-German venture designed to measure the Earth's radiation budget, will be flown on a METEOR satellite in 1993.

Two Soviet polar-orbiting ocean observing satellites are currently in operation. Almaz-1, launched March 31, 1991, carries a Synthetic Aperture Radar (SAR). Okean-3, launched June 4, 1991, has a real aperture radar and a scanning microwave radiometer.

(d) United States

NOAA Satellites. The NOAA-9, NOAA-10, and NOAA-11 satellites continued to provide the polar-orbiting service. NOAA-9, launched in December 1984, operates in a standby mode providing limited Earth Radiation Budget Experiment (ERBE) and Solar Background Ultra-Violet (SBUV) data. NOAA-10, launched in September 1986, provided the primary morning orbit coverage but was replaced in that role in September 1991, following operational checkout of the newest polar satellite, NOAA-12. NOAA-12 was successfully launched on May 14, 1991. NOAA-11, launched in September 1988, provides the primary afternoon orbit coverage.

A feasibility study for a future series of polar-orbiting satellites began in 1991, and was supplemented with preliminary design studies for upgraded and improved sensors and instruments later in the year.

The next generation of polar satellites after NOAA-K/M, will involve the sharing of common interface instruments on United States and European polar orbiters, with Europe providing a series of morning polar spacecraft and NOAA continuing its afternoon polar series.

NOAA and NASA are continuing discussions with European counterpart agencies to determine how these instruments would be integrated and how their data would be exchanged.

Landsat. Pursuant to the Land Remote-Sensing Commercialization Act of 1984, the Earth Observation Satellite Company (EOSAT) has operated both the Landsat 4 and 5 remote-sensing satellite systems for NOAA since 1985.

The National Space Council undertook a policy review of the Landsat program during 1989. At the recommendation of the Council, the President approved a policy aimed at ensuring continuity of Landsat-type data. While funding support for Landsats 4 and 5, and a new Landsat 6, has been provided, a decision on the management and funding of a satellite system following Landsat 6 has not yet been made. EOSAT is continuing to manage the design and development of a Landsat 6 system, to be launched with the new satellite, scheduled for 1992.

In 1991, 16 foreign ground stations received Landsat data. A ground station in Ecuador began operation in March 1991.

Upper Atmosphere Research Satellite. The Upper Atmosphere Research Satellite (UARS) is the first mission in the long-term international program to study global change. UARS, launched September 12, 1991, aboard Space Shuttle Discovery, is designed to study atmospheric chemistry, energy balance and dynamics. UARS will help establish the comprehensive data base needed to understand the depletion of stratospheric ozone, a component of the atmosphere essential in protecting life from harmful ultraviolet radiation. It will also contribute to the understanding of the effects of human activity on the atmosphere, and lay the foundation for a broader study of the upper atmosphere's influence on climate and climatic variations. UARS includes 10 instruments, all of which are operational. Several of these are precursors to instruments for the Earth Observing System.

Total Ozone Mapping Spectrometer. The Total Ozone Mapping Spectrometer (TOMS) instrument measures total ozone concentrations. The TOMS instrument flown on Nimbus- 7 has provided continuous data on changes in global ozone since 1978. These data were instrumental in discovering the ozone hole over the Antarctic. TOMS also provides data on lower stratosphere/tropopause dynamics. In August 1991, a TOMS instrument was flown aboard a Soviet Meteor-3 unmanned launch vehicle. The instrument is operating normally. TOMS instruments are also scheduled to fly in 1993 aboard a United States small expendable launch vehicle, and in 1995 on the Japanese Advanced Earth Observing Satellite (ADEOS), both as part of the Earth Probes program. Contractors for the instruments and for the spacecraft were selected in 1990 and 1991 respectively, and development has already begun.

(e) Japan

The Marine Observation Satellite MOS-1b, a polar-orbiting ocean observing satellite launched in February 1990, is the current operational satellite in this series. MOS-1b carries an ocean color instrument, a 3-channel visible and infrared radiometer, and a 2-channel microwave radiometer.

(f) Europe

The ERS-1, a polar-orbiting ocean observing satellite, was successfully launched in July 1991. The instrument package includes an altimeter, an Active Microwave Instrument (AMI) that provides SAR observations and surface wind and wave data, as well as an Along Track Scanning Radiometer (ATSR) for precise sea surface temperature measurements.

3. Future Platforms

(a) United States

Earth Probes. The NASA Earth Probes program is composed of a series of small- and moderate-sized missions that will address highly focused problems in Earth science. Earth Probes will provide a pre-EOS start/continuation of long-term data sets and will perform measurements that are not possible with EOS or other instrument suites. Each instrument has a specific purpose, providing critical measurements of a particular phenomenon, but requiring a unique orbit or configuration not available from other EOS precursor missions. Earth Probes are composed of the Total Ozone Mapping Spectrometer (TOMS), the NASA Scatterometer (NSCAT), and the Tropical Rainfall Measuring Mission (TRMM).

Earth Observing System. The NASA Earth Observing System (EOS) is designed to make comprehensive, long-term measurements of various aspects of the Earth system. EOS is a critical element of the Mission to Planet Earth program. The EOS program was included in the FY 1991 budget as a new start. In January 1991, 11 instruments that will monitor the Earth's surface, radiation budget, and atmospheric properties were confirmed for flight on the first EOS-A series spacecraft. At the same time, NASA also confirmed the 29 EOS interdisciplinary investigations which are critical to the scientific objectives of the program. NASA decided to delay until late 1992 the confirmation of EOS-B instruments to conduct a review of potential spacecraft configurations that would satisfy the EOS-B series science requirements. After evaluating the science requirements for the EOS-B series, NASA issued a Request for Information (RFI) to industry in late May 1991, soliciting alternative concepts and approaches to the implementation of the EOS-B series.

There was significant progress on the EOS Data and Information System (EOSDIS) during fiscal year 1991. The first major EOSDIS development product will be Version 0, a prototype system that connects a set of science users to specific existing data systems and selected data sets to test system design and integration, and to enable early research efforts in support of the United States Global Change Research Program (USGCRP). Meetings were held during the year to develop and adopt the approach to be taken to implement Version 0. The Version 0 development process, which is under way, supports on-line capability by 1994. NASA released an RFI on EOSDIS in October 1990, which produced a large number of comments and suggestions. After incorporating these comments, NASA released a Request for Proposal (RFP) for the EOSDIS Core System (ECS) contract in July 1991. It is expected that the contract will be awarded in late 1992 and that the core system will be operational by 1996-7.

The EOS Science program provides support for interdisciplinary investigations, algorithm development for facility and principal investigator instruments, and coordination with field campaigns necessary to validate and refine algorithms. The EOS Investigator Working Group (IWG), which provides guidance and advice concerning all major scientific issues relevant to the mission, met twice during FY 1991. In June 1991, an additional 61 students were selected to receive global change fellowships through a program designed to encourage the next generation of global change researchers.

International cooperation continued through meetings of the Earth Observation International Coordination Working Group (EO-ICWG) and its subgroups. The EO-ICWG is coordinating the payload planning for polar spacecraft from NASA, European Space Agency (ESA), and the Japanese Space Agency (NASDA), as well as addressing other elements of mission planning.

In 1991, due to budget constraints, emerging launch vehicle options, and other factors, NASA reevaluated its planning for the EOS program. NASA asked the IWG to give priority to the EOS science objectives and to study how the measurements required could be carried out using various spacecraft types and sizes. The reconfiguration process is scheduled to be completed for inclusion in the United States President's fiscal year 1993 budget submission.

In late September, the EOS Engineering Review Advisory Committee released its report concerning the implementation of the EOS program. The Committee considered the most critical issues facing the EOS program, including budget, scientific priorities, sensor capabilities, and spacecraft and launch vehicle options. The Committee encouraged NASA to proceed with EOS using smaller spacecraft, to foster greater cooperation with other agencies, and to conduct an additional review of the planning for the implementation of the EOSDIS core system.

(b) Soviet Union

The Soviet Union plans to launch a Geostationary Operational Meteorological Satellite (GOMS) in 1992. The major instrument is a Scanning Television Radiometer (STR) with visible, near infrared, infrared water vapor, and infrared window channels.

The USSR is also planning to launch a large, new Priroda Earth resources module to its Mir space station in 1992. The package will include visible and infrared spectrometers, a television camera, a microwave radiometer system, a SAR, and instruments to measure ozone profiles and cloud heights.

(c) France

TOPEX/POSEIDON is a joint United States (NASA) and French (CNES) mission to study global ocean circulation. Ocean circulation has a direct impact on regional climates. It also plays a key role in global climate through the absorption of carbon dioxide, an atmospheric constituent that contributes to global warming. The mission comprises highly accurate radar altimeters on a precisely tracked satellite that will observe sea surface topography. The data will enable the study and more accurate modeling of oceanic circulation and heat transport, and its interaction with the atmosphere. TOPEX/POSEIDON is a precursor to the altimetry instruments that will be included in the Earth Observing System. In 1991, the TOPEX/POSEIDON instruments were delivered and the development of the spacecraft was nearing completion. Delivery of the fully integrated satellite for launch is expected in the spring of 1992. TOPEX/POSEIDON will be launched from the Kourou launch site in French Guiana, on an Ariane IV unmanned launch vehicle.

(d) Japan

Japan's polar-orbiting Earth Resources Satellite (JERS-1) is scheduled for launch in February 1992. Instrumentation includes a Visible and Near-Infrared Radiometer (VNIR), a Short Wave Infrared Radiometer (SWIR), and a SAR, all with horizontal resolutions of about 20 m.

Japan plans to launch its polar-orbiting Advanced Earth Observing System (ADEOS) for atmospheric, oceanographic, and land remote sensing in 1995. ADEOS instruments include the Ocean Color and Temperature Scanner (OCTS) for measuring the carbon cycle, supplemented by the NASA scatterometer NSCAT and the French instrument for measuring Polarization and Directionality of the Earth's Reflectances (POLDER). In addition to the above facilities, ADEOS also includes the spectrometers TOMS and Improved Limb Atmospheric Spectrometer (ILAS), as well as the Interferometric Monitor for Greenhouse Gases (IMG) documenting atmospheric profiles.

The Tropical Rainfall Measuring Mission (TRMM) will measure diurnal variation of precipitation and evaporation in the tropics, providing insight into the way substantial rainfall affects global climate patterns. TRMM is a joint United States/Japan venture, and will be launched on the H-II launch vehicle in the late 1990s. In 1991, Phase B definition studies for TRMM were completed, and design and development were begun. TRMM is scheduled for launch into a low latitude orbit in 1996 and will carry a precipitation radar, a visible and infrared scanner, a microwave imager, and an ERB instrument.

(e) Canada

Canada plans to launch a radar satellite--Radarsat--in 1994. Radarsat will carry an SAR for high-resolution studies of arctic ice and agricultural, forestry, and water resource management applications.

D. International Committee Activities

1. World Meteorological Organization (WMO)

The Eleventh World Meteorological Congress, which met in May 1991, recognized the critical need to continue the operation of environmental satellite systems and appealed to operators to ensure the continuity, quality, and coverage of their satellite programs. The 43rd session of the WMO Executive Council emphasized the important role of satellites in all WMO programs and took steps to ensure appropriate coordination of satellite activities among members.

2. World Meteorological Organization Panel of Experts on Satellites

In March 1991, NOAA participated in the Ninth Session of the Executive Council Panel of Experts on Satellites of WMO. The purpose of the Panel is to advise the WMO on technical and programmatic matters relating to meteorological systems and their contributions to WMO programs.

The Panel discussions focused on 1) an appropriate WMO structure for its satellite activities; 2) WMO relationships with international satellite coordination groups; and 3) satellite data requirements. Panel recommendations included: 1) restructuring of satellite activities within the WMO Commission for Basic Systems, 2) defining and establishing closer relationships and interactions with international satellite operator coordination groups, and 3) recognizing the need to develop satellite data so as to meet the requirements of such satellite operator groups.

3. Coordination of Geostationary Meteorological Satellites

The Coordination of Geostationary Meteorological Satellites (CGMS) group met in Tashkent, Uzbekistan, in December 1990. It serves as an informal technical forum through which independent national meteorological satellite programs are harmonized in order to achieve the common objectives in meteorological missions. The membership, including the European Meteorological Satellite Program (EUMETSAT), India, Japan, the United States, USSR, China, and WMO, adopted a provisional charter according to which the group is renamed "Coordination Group for Meteorological Satellites" (CGMS), and will expand its mandate to encompass technical and operational matters involving polar-orbiting meteorological satellite systems, in addition to geostationary satellite systems. CGMS seeks to harmonize, to the extent possible, meteorological satellite mission parameters such as orbits, sensors, data formats, and downlink frequencies.

4. Committee on Earth Observation Satellites

The Committee on Earth Observations Satellites (CEOS), formed in 1984 as an outgrowth of the international Economic Summit of Industrialized Nations, serves as the coordinating forum for the overall Earth observations space community. At the November 1990 CEOS plenary meeting, NOAA and NASA secured the adoption of a proposal for strengthening CEOS interaction with both international scientific programs (International Council of Scientific Unions/

International Geosphere-Biosphere Program, World Climate Research Program) and intergovernmental user organizations (Intergovernmental Panel on Climate Change, Intergovernmental Oceanographic Commission, WMO, United Nations Environment Program). The aim is to enhance Earth observation mission planning by focusing space agencies' attention on global change program requirements. Scientific and intergovernmental agency representatives have been invited to participate in CEOS deliberations and technical coordination activities. Moreover, CEOS members agreed to provide to the international community non-discriminatory and full access to their Earth observation data.

The goal of the CEOS Working Group on Data (WGD), chaired by NESDIS, is to facilitate the use of data from Earth observation missions by coordinating and standardizing aspects of data management where possible. WGD has created specialized technical subgroups to address specific issues in detail and has established pilot projects and prototype systems to demonstrate and evaluate internationally coordinated approaches to Earth observations data management. Among the achievements of the WGD are: 1) development and support of standard data formats for digital user products; 2) establishment of the CEOS WGD Library; 3) development of an International Directory Network system; 4) creation of a group to explore the need to set up networks for the exchange of data after reception on the ground; and 5) introduction of tutorials on data format and format standards for use in training data managers.

5. International Polar-Orbiting Metereological Satellite Group

The 1984 Economic Summit of Industrialized Nations endorsed the creation of the International Polar-Orbiting Meteorological Satellite Group (IPOMS) to explore the mechanisms for increasing international cooperation in support of polar-orbiting meteorological satellites and to ensure their continuity.

Since the September 1990 IPOMS plenary in Venice, Italy, NOAA and NASA have continued to explore with European counterpart agencies (EUMETSAT and European Space Agency (ESA)) arrangements to fly United States instruments as part of ESA's Polar-Orbiting Environmental Mission payload, and to fly European instruments on future NOAA polar-orbiters.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS, AND SMALL BODIES OF THE SOLAR SYSTEM

A. The Terrestrial Planets

1. Venus

Analysis of Venera 15/16 radiometric data led to the construction of a map of effective temperature of the surface of Venus from 10 to 90 Northern latitude.

The Magellan spacecraft was successfully put into orbit in August 1990. After some initial difficulties, it proceeded on its mission to map the entire planet and is (September 1991) beginning a repetition of that global map at the present time. This repetition will permit the spacecraft to map areas of Venus which were missed during the first cycle (which covered 84 percent of the planet) and will also allow a search for changes in the landscape that may have occurred as a result of "earthquakes", volcanic eruptions, etc.

One of the highlights of this exploration has been the absence of any evidence for plate tectonics on Venus in the data examined to date. Although many impact craters have been found, large areas of the surface of Venus are sufficiently young so that no impacts are visible. Some expanses of terrain show orthogonally intersecting sets of lineations, a landform not seen before on other planets or satellites. Domes of various sizes thought to be associated with volcanic activity have been identified, including a curious set of seven 24 km diameter "pancakes" that are just 750 m high. There is no certain indication yet of contemporary volcanism, but the new mapping cycle may find such activity by allowing comparisons with the previous one.

Galileo preceded Magellan to Venus, arriving in February 1990. The need to keep the Galileo high-gain antenna furled as a precaution against excessive heat meant that the full data set from this encounter could not be returned to Earth until the spacecraft passed our planet in November 1990. The data sent back at that point have not yet been fully analyzed, but several striking results have already emerged from the NIMS experiment. These include the exploitation of windows in the infrared spectrum of Venus to probe the lower atmosphere and surface of that planet. The results to date indicate a maximum column abundance of water vapor in the atmosphere of 75 ppm. Galileo found an infrared window at 1.00 micrometers in addition to those already known at longer wavelengths, which may have allowed the spacecraft to sense the planet's surface. Contrary to terrestrial experience, the opacity of the atmosphere of Venus appears to decrease with decreasing wavelength over the range of 1.0 to 2.5 micrometers.

2. Mars

Analysis of data from the Phobos 2 mission, by processing data of mapping spectrometry in the 0.8 to 3.2 micrometer range, led to high-resolution topographic maps for the equatorial zone of Mars. All the spectra of the surface show the hydration band, but its intensity varies from place to place.

Preparations are in progress for the launch of Mars Observer, in the window from September 16 to October 6, 1992. The corresponding arrival at Mars will be between August 19 and September 7, 1993. It will have been 17 years since the last United States spacecraft, the highly successful Viking (July 1976), visited the red planet.

Preparations continue in the Soviet Union for the ambitious international project Mars-94. Further missions to the red planet, including long-duration stations, penetrators, balloons and rovers, are either in preparation or in planning in the Soviet Union, Japan and by NASA and ESA for a 1996 and later launch.

3. Phobos

The combination of data from the KRFM and ISM experiments of Phobos 2 provided the possibility of obtaining a continuous spectrum of Phobos in the range of 0.31 to 3.2 micrometers. This spectrum differs clearly from spectra of carbonaceous chondrites, earlier thought to be analogs of Phobos material.

Independent analyses, by Soviet and United States groups, of gamma-spectrometer data led to estimations of the abundance of Martian surface material which are in good agreement with each other. There is some indication of regional variations in the surface chemistry.

4. Moon

The Japanese ISAS satellite Hiten was launched in February 1990 to perform the lunar swingby, which is an essential technology for future Japanese missions. After successful manoeuvres for 9 lunar swingby's, two aerobreaking experiments in the Earth's atmosphere were performed.

A Lunar-A mission is planned in Japan for 1996. The aim of the program is to explore the lunar interior with a network of three penetrator-stations, seismometers and heat flow probes. The seismometers' sensitivity is of 10-9 cm/sec^2. The data will be transmitted to Earth via a polar orbiting spacecraft.

B. The Outer Planets

1. Jupiter

The Galileo spacecraft is presently on the outbound leg of its first Earth orbit, having successfully encountered Venus and the Earth-Moon system. Unfortunately, a problem has developed with the high-gain antenna since it has not been possible to unfurl it completely from its stored, sun-protected position. Three attempts, using differential expansion or contraction, have been made to free the ribs of the antenna, to no avail. A fourth attempt will be made in December 1991, when the spacecraft is farthest from the Sun. It is hoped a temperature drop of 50 C can be achieved at this time.

2. Saturn

The development phase of the NASA-ESA Cassini-Huygens mission is proceeding as planned after payload selection in November 1990. The launch is scheduled for 1996.

C. Small Bodies in the Solar System

1. Asteroids

The first asteroid flyby ever achieved by any spacecraft is scheduled to occur on October 29, 1991 when Galileo encounters Gaspra. The problems with the high-gain antenna described above will delay the data return until the next Earth encounter in December 1992. At this point the low-gain antenna can be used, as it was for the transmission of Venus encounter data. The

Gaspra encounter sequence was successfully updated with the help of ground-based observations of the asteroid last summer.

2. Comets

The Comet Rendezvous Asteroid Flyby (CRAF) mission is proceeding in parallel with Cassini. A readjustment of launch dates (required by a slip in the schedule) has led to the selection of comet Temple II as the target comet, with the rendezvous to start in January 2003.

The Giotto extended mission is preparing to investigate Grigg-Skjellerup's comet, using the same Giotto spacecraft which was used to study Halley's comet in 1986. The new orbit was reached -through complicated Earth-swingby manoeuvres.

3. Dust

Experiments to study interplanetary dust are parts of the Galileo and the Ulysses missions, with a sensitivity for the mass detection up to six orders of magnitude better than earlier measurements in the asteroidal belt and in the outer solar system. The experiments are functioning well. Further dust measurements are incorporated in the COMA experiment of the CRAF mission, with dust analyzers in both the Cassini mission and the Giotto extended mission. Dust investigations are also part of the observation programs of the Hubble Space Telescope and the ISO experiment.

D. International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG)

The CSTG has promoted and fostered space tracking activities on an international level for various projects directed at high precision requirements of space geodesy, geodynamics and other disciplines. Widely used techniques now include Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR), Very Long Baseline Interferometry (VLBI) and Global Positioning System (GPS). The new technique of DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) is beginning to make scientific contributions and PRARE (Precise Range And Range-rate Equipment) is expected to do so in the near future. Some of the major achievements within the reporting period are summarized in the following.

1. International Earth Rotation Service (IERS)

The IERS began operation on January 1, 1988, and is directed by a Board consisting of representatives from the International Astronomical Union (IAU), the International Union of Geodesy and Geophysics (IUGG), and coordinators from each of the contributing space techniques. The IERS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and is located at the Paris Observatory. The IERS uses VLBI, SLR and LLR to define and maintain a conventional terrestrial reference frame, to determine Earth orientation parameters, and VLBI for defining and maintaining a conventional celestial reference frame based on extragalactic radio sources. During the reporting period, the IERS chose a coordinator for GPS (JPL) for the purpose of evaluating the contributions this constellation of satellites can make to the IERS. An international workshop was held in Mizusawa, Japan, in May 1991, to review and discuss the IERS products.

2. VLBI Activities

The basic measurement of VLBI is the time delay of the arrival of signals received at two or more ground-based antennae from distant radio sources, typically quasars. The determination of the time delay is obtained from the cross-correlation of the recorded quasar signals. In the reporting period, enhancements to existing VLBI networks have taken place and new networks have begun operation. The longest regularly operating VLBI network is known as IRIS-A, currently consisting of 3 observatories in the United States (Westford, Mojave, Richmond) and observatories in Germany and Sweden. The IRIS-P, begun in 1987, consists of observatories in the United States (Fairbanks and Mojave), Japan (Kashima) and Australia (Hobart). A Southern hemisphere network (IRIS-S) consisting of South Africa, Australia and the Antarctic has begun operation. New sites in South America are scheduled and the United States Naval Observatory has begun operation of a network (NAVNET) consisting of sites in Alaska, Hawaii, California and Florida. A new network in the USSR, known as QUASAR, is being deployed. New stations in China, Chile and Italy have begun operation.

Mobile VLBI measurements for precise positioning have taken place in Europe and the United States. In some cases, the measurements have been conducted at sites with either fixed SLR or at which transportable SLR measurements have been obtained, thereby providing data for use in collocation investigations and the determination of common reference frames. It is generally reported that VLBI can achieve baseline precision of a few parts per billion.

Further information about VLBI, especially contributions to the IERS, can be found in the *IERS Annual Reports*. A CSTG Subcommission on VLBI, or the IRIS Subcommission, issues regular reports on the status of VLBI.

3. Laser Ranging Activities (SLR and LLR)

As part of a global network, laser ranging stations cooperate in the laser tracking of several satellites. The basic SLR measurement is the round trip time required for a laser pulse to travel from the transmitting observatory to a satellite, where it is reflected, and back to the observatory. The primary target of these stations is LAGEOS (altitude: 5900 km; inclination: 110 degrees), used for determination of global reference frame, Earth rotation parameters and study of the gravity field of the Earth, including temporal variations in the gravity field. Improvements in force modeling over the last few years have enabled determination of the LAGEOS orbit to the few decimeter accuracy level.

Other satellites currently tracked by SLR for applications similar to LAGEOS include Starlette (altitude: 900 km; inclination: 50 degrees) and Ajisai (altitude: 1500 km; inclination: 50 degrees). In 1989, two new satellites were launched by the Soviet Union, Etalon-1 and Etalon-2, into GLONASS-type orbits of 19,000 km altitude and inclination of 63 degrees. The IERS organized a campaign in late 1990 for the tracking of the Etalon satellites and a scientific symposium to review results was held in Moscow (June 1991). CSTG issues reports on SLR activities.

During the reporting period, mobile SLR stations were deployed for precise determination of reference points in support of Earth crustal motion measurements or for the purpose of collocating with other techniques, particularly VLBI. The current inventory of transportable SLR systems includes: United States-4, The Netherlands-1, Germany-1 and Japan-1. In July 1991, the German system began a series of collocation experiments at SLR stations in the USSR. Precise geodetic positioning results show that the SLR and VLBI reference frames agree at the few centimeter level, after adjusting for the origin, rotation and scale differences.

New SLR stations began operation in the reporting period, including stations in Japan (Tokyo), Germany (Wettzell) and USSR (Glavkosmos stations at Maydanak, Dunaevec and Evpatoriya). Testing of a new system for Saudi Arabia began in 1991. The global contributing stations are summarized in the *IERS Annual Report* for 1990.

In addition to the contributions of SLR to geodesy and geodynamics, the systems are also used to provide precise determinations of orbits. Most recently, SLR is being used as the primary tracking mode for the European Space Agency Earth resources satellite, ERS-1.

The primary LLR sites are located at McDonald Observatory (United States), Grasse (France), Mt. Haleakala (United States). The LLR systems utilize laser pulses targeted at reflectors implanted on the lunar surface by the USSR (Lunakhod) and the United States (Apollo). The LLR technique makes significant contributions to the IERS through determination of Universal Time.

4. GPS Activities

The role of GPS (altitude: 19,000 km; inclinations: 63 degrees (Block I) and 55 degrees (Block II)) in space geodesy has continued to expand and blossom. Numerous campaigns have been conducted during the reporting period for the purpose of making measurements of crustal motion. These campaigns have covered many geographical areas of the world: for example, Central and South America, S. Pacific, Indonesia, Japan. Under the IERS, a global campaign (GIG '91) was organized to determine the ability of GPS to support IERS needs (Earth rotation and reference frame), as well as to support regional measurements of crustal motion. A workshop to review preliminary GIG results was held in Ahrweiler (Germany) in August 1991. Results have been presented that demonstrate the ability of differential GPS techniques to produce relative positioning at a level of several parts in a billion.

At the IUGG meeting in Vienna (August 1991), plans were presented for the establishment of an International GPS Service that, ultimately, would regularly provide Earth rotation products and GPS ephemerides to the scientific community. A 3-month international campaign is scheduled in mid-1992 as a demonstration of capabilities.

An international cooperating network of GPS receivers, known as CIGNET, has been collecting data from sites collocated with VLBI or SLR. The CIGNET has supported most GPS regional campaigns by providing fiducial data. A CSTG Subcommission on GPS regularly reports on the status of GPS in general, as well as the status of the CIGNET.

Preparation of a demonstration of GPS capabilities for precise positioning of an orbiting platform proceeded under the TOPEX/Poseidon Project, scheduled for launch in mid-1992. Tracking of this satellite, designed for studies of ocean circulation using radar altimetry, will be accomplished using SLR, a GPS receiver and DORIS (see below). The use of all three techniques will provide a rich intercomparison experiment.

The precise modeling of nongravitational forces has moved into a level of prominence for precise orbit determination in support of oceanographic and geodetic applications. Such forces include drag, solar and Earth radiation and thermal imbalance forces and are well known for the limits they often introduce on precision orbit determination. Considerable effort is being devoted to examination of such forces for ERS-1, GPS, LAGEOS and TOPEX/POSEIDON, for example.

5. DORIS Activities

The DORIS system was launched during the reporting period with the French SPOT-2 satellite. DORIS is based on the operation of ground-based beacons transmitting on two frequencies for the removal of the ionosphere effect. Approximately 40 beacons are located with a generally favorable geographic distribution and some DORIS beacons are collocated with VLBI or SLR sites. Recent results have shown that precise geodetic positioning can be obtained from DORIS and that the favorable geographic distribution of beacons enables improved parameterization of nongravitational forces.

6. Related Activities

The PRARE system will be operated in space for the first time with the launch of ERS-1. The system is expected to be used on some future satellites as well.

The precise intercomparison of results from the various techniques is essential for the establishment of the accuracy of those techniques, since for the most part, the error sources in each technique are somewhat technique-dependent. A CSTG Subcommission is to address site issues, for example, site stability that could limit or unknowingly influence technique intercomparisons or the geophysical interpretation of space geodetic measurements.

III. SPACE STUDIES OF THE ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

A. The Earth's Middle Atmosphere

Both experimental and theoretical studies of the Earth's middle atmosphere have progressed significantly in the last two years. In the following some examples will be presented.

The International project DYANA (Dynamics Adapted Network for the Atmosphere) was performed in early 1990, at various places on the globe, for case studies of middle atmosphere dynamics up to about 100 km. The main emphasis of this campaign was on global aspects of planetary waves, gravity waves and turbulence. Numerous ground-based, balloon and rocket borne experiments were involved. The first results show that large scale variations of the winter middle atmosphere are determined by long period oscillations with periods around 5, 7.5 and 12-days. First analysis of *in situ* turbulence measurements indicates that the middle atmosphere was very quiet at high and middle altitudes during DYANA.

The study of fine structure layers was continued in the last two years. Theoretical models and inter-comparisons of *in situ* and ground-based measurements of the thermal, dynamical, electrodynamical and plasma status of the atmosphere gave more insight into the processes which create these layers and which determine their visibility by remote sounding. In August 1991, a campaign called NLC-91 was performed at Esrange (Sweden) with special emphasis on noctilucent clouds (NLC) and polar mesosphere summer echoes (PMSE). Both ground-based (e.g.radar) and *in situ* (rocket) instruments were used to study in detail the fine-scale structure of these layers and their role in the backscatter mechanism for radars. One rocket salvo was launched into a strong NLC event. The data evaluation is currently under way.

The data collected in the middle atmosphere over the past years now make it possible to study long-term effects in this region, such as climatological trends or a possible correlation between the 11-year solar cycle and the thermal and dynamical properties in this part of the atmosphere. There is now some observational evidence for a long-term decrease of mesospheric temperature on the order of a few Kelvin per decade.

The coupling mechanisms between the middle atmosphere and the layers above and below have been studied both by numerical experiments and by remote sounding (mainly radars and lidars). The efforts have been internationally coordinated in programs such as CEDAR (Coupling, Energetics and Dynamics of Atmospheric Regions), UCWE (Upward Coupling of Wave Energy), or MLTCS (Mesosphere, Lower Thermosphere Coupling Study).

Satellite observations and parallel theoretical efforts have played a central role in facilitating rapid progress. Observations by the Stratospheric and Mesospheric Sounder (SAMS) and the Limb Infrared Monitor of the Stratosphere (LIMS) provided data on atmospheric composition and dynamics on a global scale. SME made global measurements of ozone and other minor constituents in the middle atmosphere, as well as measurements of temperature over a period of several years. Observations of ozone and aerosols from the Stratospheric Aerosol and Gas Experiment (SAGE) and of the total ozone content from the Total Ozone Mapping Spectrometer (TOMS) have also played an important role, especially in recent studies of polar ozone depletion. Spacecraft observations have also determined the response of ozone concentrations to 27-day and solar-cycle variations in ultraviolet radiation.

B. The Earth's Upper Atmosphere and Ionosphere

During the two-year period under review the national and international space research efforts devoted to the study of the thermosphere and ionosphere have been limited by the relatively small number of dedicated rocket and satellite launches which have occurred.

The last major spacecraft dedicated to research in this field was the San Marco spacecraft launched in March 1988. The preliminary results from this mission were presented in a special session on "Equatorial Aeronomy" at the 1990 COSPAR meeting in The Hague. Observational data were provided on electric fields, the neutral upper atmosphere and the ionosphere, as well as on precipitation of energetic particles and solar ionizing fluxes.

Individual instruments have been flown on a number of spacecraft dedicated to other primary purposes. Examples of this are the Space Environment Monitors on the NOAA/TIROS spacecraft which define and routinely monitor the energetic particle fluxes incident on the upper atmosphere. Future NOAA/TIROS spacecraft will also carry the Remote Atmospheric and Ionospheric Detection System (RAIDS), which will monitor the density distribution of thermospheric and ionospheric species by means of limb scanning from a high-inclination orbit near 800 km altitude. The United States DMSP spacecraft will also carry instruments which measure ion drifts and field aligned currents, in addition to the energetic particle precipitation incident on the upper atmosphere. The exploitation of data from these and other orbital instruments (including instruments on spacecraft devoted primarily to magnetospheric or plasma physics research), in combination with data from networks of ground-based instruments, made it possible to carry out a series of cooperative programs for studying solar and geomagnetic activity conditions.

The primary measurements of solar and magnetospheric energy inputs to the thermosphere and ionosphere can also be used to define the inputs to global numerical models. Such models can now provide near real-time computations of the overall qualitative response of the thermosphere and ionosphere. There remains the major problem of obtaining indices related to solar and geomagnetic activity, which faithfully reproduce the highly detailed and time-dependent patterns of auroral precipitation and plasma convection. There are no space missions planned for investigating one of the critical outstanding issues: the global measurement of mesospheric, thermospheric and ionospheric dynamics. These interrelated motions control many aspects of the chemical and energetic behavior of the upper atmosphere and ionosphere. The current state of knowledge is dependent on a highly fragmentary data base and numerical models. Due to the shortage of real observational data, these numerical models have unfortunately never been validated.

The global electric circuit is largely driven by the external magnetospheric convective field at high latitudes and by the global E-region dynamo with an internal source, mainly thunderstorm generated fields in the lower atmosphere. Investigations of the global electric circuit have been reactivated as a result of the discovery of occasional but unexpectedly large middle-atmosphere electric fields. Combined studies using rockets and ground-based radars and lidars were carried out in the summer of 1991 to observe the behavior of the high-latitude summer mesopause and lower thermosphere, in order to study the combined chemical, dynamical and electro-dynamical behavior during polar mesospheric cloud periods, and during noctilucent cloud events.

Considerable progress in thermospheric and ionospheric studies is now emerging from ground-based optical and radar measurements. This empirical work is strongly supported by major research programs using sophisticated numerical models of the coupled atmosphere-ionosphere regions. Further valuable information on the magnetospheric inputs of energy and momentum comes from monitors in meteorological program spacecraft in low Earth orbits. These measure energetic processes, auroral emissions, electric fields/ion drifts and field aligned currents. Unfortunately, none of the major space agencies has included in its plans significant resources for appropriate direct and remote sensing observations of the thermosphere and ionosphere, using a coordinated package of synergetic instruments prior to the ESA/NASA polar platforms in the late 1990's. Valuable measurements of the lower thermosphere will be made in the 1991-1992 period from NASA's Upper Atmosphere Research Satellite (UARS).

The CRIT 11, PEGSAT and the first series of CRRES chemical release experiments have been successfully completed. A second series of CRRES chemical release experiments occurred during 1991. Injection experiments such as ARCS, SPEAR and NEED have taken place and further experiments in these series are being planned for the future, including wave injection experiments combined with ground-based ionospheric heating.

The Solar Terrestrial Energy Program (STEP) is planning and implementing a number of projects within the field of ionosphere/thermosphere/middle atmosphere physics. It should be stressed that long-term ground-based observations will play a key role in the study of the climatology of the space environment. Some progress has recently been made in modeling the long-term change of ionospheric variability. The combination of ground-based and space observations is particularly important in the development of the International Reference Ionosphere (IRI).

C. Planetary Atmospheres and Aeronomy

Analysis of data of the scientific experiments of the Phobos mission (1989) has been successful. Altitude profiles of water vapor and aerosols in the atmosphere of Mars were found for the first time. A mean mixing rate of H_2O about 150 ppm below 12 km and 3 ppm at 40 km was estimated. Mineral dust haze profiles show a sharp decrease at a height about 25 km. Layers of ice particles were identified at heights between 50 and 70 km. All these data were collected at nearly equatorial latitudes after spring equinox. The optical depth of dust ($\tau \sim 0.2$) is less and the particle size distribution is narrower ($\gamma = 1$) than it was at the time of the Viking landers measurements for the same season. Atmospheric aerosols are an important component in the climatic processes on Mars and the new clarification of their properties represented a very important step. The next step will probably be taken by the American Mars-Observer (1992) and the Soviet Mars 94/96 missions.

The Galileo mission to Jupiter is under way and the probe is functioning well. The Cassini-Huygens probe has been approved by NASA and ESA. The Giotto probe has been reviewed by ESA and a decision has been made to prepare for an encounter with the Grigg-Skjellerup comet.

The COSPAR Task Group on the Venus International Reference Atmosphere (VIRA) met during the XXVIII meeting of COSPAR in The Hague, primarily to discuss the necessity of updating the VIRA document which was published as N .11, Vol. 5 of *Advances in Space Research* in 1985. Since then, it has become a much consulted reference work on the Venus atmosphere and ionosphere, but it has been out of print for some time. It was decided that the publication of a completely updated VIRA document must await not only new data, to be provided by the low-periapsis phase of the Pioneer Venus mission which will occur in 1992, but also contributions of radio occultation measurements from the Magellan mission. Thus it will not be possible to start with the editorial process before 1994. A separate issue in *Advances in Space Research* will be devoted to the updated version of the chapter on the Venus ionosphere, for which much new material has been collected since its first publication.

D. Trace Species of the Earth's Atmosphere

The Task Group on International Reference Atmospheres of Trace Species was established by COSPAR in 1990. This task group is compiling a *Part 3 on Trace Species* for the *COSPAR International Reference Atmosphere (CIRA)*. Reference models which are being developed include O_3, N_2O, HNO_3, CH_4, CFC's, aerosols and polar stratospheric clouds in the middle atmosphere, and NO, O, and H in the lower thermosphere. In accordance with a proposal of the MAP Steering Committee of SCOSTEP, an early version of many of these reference models has just been published as *MAP Handbook 31* for distribution to and feedback from the international scientific community, prior to the publication of *Part 3 of CIRA*. The models may be used as a common means of comparison of measurements, as a common reference model for comparison with theoretical studies, and as a common input where measurements are dependent on "first guess".

An international workshop on trace species was held at the 1990 COSPAR meeting. New information included: water vapor measurements in the stratosphere and mesosphere from Nimbus 7 SAMS; an extension of the ozone reference model down to 70 mb using SAGE data; a reference model of atomic oxygen as a function of latitude, month and pressure which is consistent with the mesospheric ozone data and the MSIS model; and a model of atomic hydrogen near the mesopause, consistent with Solar Mesospheric Explorer data.

The second volume of CIRA (D. Rees, J.J. Barnett and K. Labitzke, eds.) entitled *COSPAR International Reference Atmosphere: 1986 Part II; Middle Atmosphere Models* has now been published by Pergamon Press as *Advances in Space Research, vol. 10, N 12, 1990* (519 pages). This book contains an earlier version of the ozone reference model (pages 315-356) being developed for CIRA Part 3. The ozone distribution is given as a function of latitude, month and pressure (altitude) from 25 to 90 km. The tables and standard deviations are based on combined data from 6 satellite experiments.

At the end of 1990 the URSI/COSPAR Task Group on the International Reference Ionosphere (IRI) released the newest version of IRI. The *IRI-90 Handbook* (155 pages) was published in November 1990 with the help of NASA's National Space Science Data Center (NSSDC) in Greenbelt, Maryland, as *NSSDC/WDC-A-R&S Report 90-22* (D. Bilitza, ed.). It describes the IRI model in text and figures and summarizes the work of the IRI Task Group over the last decade. In early 1991 the IRI-90 computer software became available from NSSDC on tape, diskette, and on-line on computer networks (NSI-DECnet address: NCF::REQUEST).

In accordance with IRI's original character, the plasma temperatures in IRI at the lower boundary (120 km) are tied to the CIRA neutral temperature. The most recent version of CIRA is now used for this purpose.

During the last IRI meeting, in The Hague, the next improvement cycle was initiated with an assessment of existing data bases and future data needs. The importance of long-lasting consistent observation programs was stressed. Conservation of older space and ground data is a prerequisite for understanding solar cycle effects. Cross-calibration between data records of different measurement techniques was seen as a crucial tool in making full use of past data records. Ongoing efforts in global and regional descriptions of ionospheric parameters was reviewed during the IRI workshop in Athens, Greece in October 1991.

The most visible progress of the 1990-1991 year was the launch of the NASA CRRES program (Chemical Release and Radiation Effects Satellite) which released 24 canisters of both alkali earths and metals and also plasma depleting chemicals to study the behavior of the ionosphere under a variety of perturbations. Important objectives were studies of the Alfven Critical Velocity Effect, the motions of artificial ion clouds in the magnetosphere, and studies of the momentum and energy coupling between fast-moving clouds and the background ionosphere. By late October 1991, all releases had been performed successively and an intensive analysis phase has begun.

Unfortunately, several other active programs have been delayed. In particular, the APEX program in the USSR, the launch date of which was planned for November 1991, has been postponed for at least one year. Also, some seven sub-orbital launches from Puerto Rico were delayed for programmatic reasons in the United States. However, the WISP 1 flight to study VLF wave effects was successfully launched.

These programs will be launched during the next year, and intensive analysis from several past programs will continue. With the launch of APEX and analysis of CRRES, there should be a lively meeting on active experiments at the next COSPAR meeting in Washington, DC.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM

The most tenuous parts of the solar system are in the plasma state, the upper levels of the Earth's atmosphere, the outer corona of the Sun, the solar wind, the ionized atmosphere of each of the planets, the magnetospheres of Jupiter and Saturn and the extended plasma environments of comets. The bulk of our firm knowledge of the physics of plasmas in space comes from measurements made *in situ* by space probes. Substantial additional information has come from balloons, rocket probes and ground-based facilities, such as radars.

All the planets of the solar system, as far out as Neptune, have now been visited by spacecraft. Orbiters have studied the plasma environment of Mars, Venus, and an orbiter (along with a probe) is on its way to Jupiter. There have been several launches of missions carrying payloads with instrumentation for investigation of the solar system plasma environment. The use of Earth and Venus for gravity-assist manoeuvres has brought new "science of opportunity" for the field. The joint American-European Saturn orbiter and Titan probe (Cassini-Huygens), to be launched later in the decade, is now under way with the selection of its science instrumentation team.

The major launch of the past year was the Ulysses spacecraft which was put into space by the Space Shuttle in October 1990. The spacecraft has been put into a direct orbit to Jupiter and is currently the fastest man-made object ever created. Pioneers 10 and 11 and Voyagers 1 and 2 continue to probe further from the Sun. We await the first indication of the heliopause, the boundary of the heliosphere, marking the limit of the Sun's direct influence in space. In near Earth orbit, the ACTIVNY and CRRES spacecraft are now sending back data. Their first results have also made this an important year for terrestrial space plasma physics.

Heliospheric work has started a new period of activity with the October 1990 launch of the long-delayed ESA/NASA Ulysses spacecraft. The Ulysses mission is designed to explore the interplanetary medium, the solar wind, the solar magnetic field, and the access of cosmic rays in regions significantly out of the ecliptic plane. The spacecraft is now well on its way to Jupiter where a gravity-assist manoeuvre in February 1992 will send it out of the ecliptic plane to explore over the poles of the Sun. Ulysses will introduce the third dimension to our understanding of the heliosphere which, at present, can be studied only by rather indirect means such as the examination of interplanetary radio scintillations. Prior to the start of their prime mission activities, both Galileo and Ulysses have been monitoring the interplanetary medium during a time of extreme disturbance. The coverage of interplanetary space from Ulysses is essentially continuous and the current data look extremely interesting. What might have seemed a dull cruise in the ecliptic out to Jupiter is turning out to be very exciting in the light of the extreme levels of solar activity. It is worth noting that the phase of the solar cycle during which this cruise is taking place is very different from that of any of the previous Pioneer and Voyager spacecraft that have gone as far as Jupiter's orbit.

No spacecraft has yet reached the edge of the solar influence in the interstellar medium, the hypothetical boundary known as the heliopause. Pioneer and now two Voyager spacecraft are heading out of the solar system and must eventually reach the interstellar medium beyond the heliopause. The most distant spacecraft is Pioneer 10, which is now well beyond 50 Astronomical Units (AU) from the Sun. Pioneer 11 and the Voyagers complete the set of outer heliospheric probes.

The planning for the Ulysses Jupiter encounter in February 1992 is well under way. This is likely to be the next major event in planetary space plasma science. Once again, as in its pre-Jupiter cruise -phase, there are unique differences between the Ulysses Jupiter flyby trajectory and that of any previous spacecraft, and so new science is confidently expected.

The Galileo Jupiter orbiter, making its way slowly through the solar system to its rendezvous with the planet later in the decade, has also been able to monitor the solar activity this year. In addition, it has made contributions to our knowledge of solar planetary plasma science through its flybys of Earth and Venus. In February and December 1990, the Galileo spacecraft made close flybys of Earth and Venus in order to gain energy for the complex journey required to get such a large orbiter and probe package to the Jupiter system. Galileo's flyby of Venus earlier in the year was expected to produce little in the way of interesting information on the Venus plasma environment; this prognostication proved very wrong. The orbit produced multiple crossings of the planetary bow shock in a (weak shock) parameter regime that is never encountered at Earth. Much upstream wave and particle phenomena were detected and will be subject to detailed analysis in coming months. Galileo was the first spacecraft capable of measuring energetic particles upstream of Venus to flyby the planet.

The Galileo Earth encounter took the spacecraft on a long pass more or less up the axis of the Earth's magnetotail, rapidly around the planet and out through the dayside magnetopause at a speed of 14 km/s. The magnetosphere cooperated by putting on a display of varied geomagnetic activity during the 24-hour period of encounter. Large amounts of correlated ground-based data were obtained and a rich scientific harvest is expected in the next year or so.

There is another Galileo Earth encounter due in December 1992, and it is hoped that this will result in more solar terrestrial science. At the moment, the failure to deploy the large antenna, essential for Jupiter orbital science, remains the major question mark over the long-term success of the mission.

The Japanese Akebono (EXOS D) spacecraft is also continuing to provide new material concerning the Earth's magnetosphere. Akebono is one of the first spacecraft in a major, internationally coordinated effort to study the solar terrestrial system. During the nineties, space agencies in the United States and Japan, ESA in Western Europe and Intercosmos in Eastern Europe are putting together a large multi-spacecraft program to investigate plasma processes in the near Earth space for the next decade. The next major Japanese contribution is the Geotail spacecraft, which is to be launched in the next year and will explore the magnetotail of the Earth's magnetosphere. NASA spacecraft will monitor conditions upstream of the system in the solar wind and the distant polar magnetosphere. This phase will be followed by the ESA-led Cluster mission, where four spacecraft will fly in close formation to study the field and plasma microstructure in the magnetosphere, in coordination, it is hoped, with a parallel Soviet spacecraft program.

Cluster is a four-spacecraft mission designed to study in detail processes such as magnetic reconnection, hydromagnetic waves and turbulence which occur in other solar, planetary and astrophysical contexts. These can be studied *in situ* in a manner impossible in other situations. The boundary regions between the magnetospheric and solar wind plasmas are the site of a variety of anomalous plasma phenomena which are not well understood, and doubtless fundamental physics will result from the first use of multi-point measurements in the high altitude magnetosphere. Coordinated modeling programs are receiving increasing attention with a major workshop taking place in September 1991 to initiate the latter effort.

A newly launched solar terrestrial physics program is the CRRES (Combined Radiation Release Experiment) mission. This was successfully launched from Kennedy Space Center, United States in August last year and is providing the first survey of the radiation belts of the Earth since the late sixties. Indeed, the spacecraft is probably flying the most comprehensive set of charged particle detectors ever flown in a magnetospheric spacecraft. The spacecraft has also started to perform a series of controlled release experiments at both low and high altitude, to examine both the physics of the release process itself and the use of the release particles as tracers of natural phenomena. The Soviet Activny spacecraft has been launched and coordinated studies with ground-based sites and other spacecraft are under way. COSPAR Commission D has expanded its activities related to active experimentation in space.

Soviet scientists are leading an Interkosmos multi-spacecraft program, Interball, which is also directed at the study of magnetospheric plasma processes. In some respects a development of the recent Dynamics Explorer and Viking projects, the program will feature pairs of spacecraft, in low and high orbit respectively, with the aim of further studying the interrelationship of ionospheric and magnetospheric processes.

The area of research is active with exciting programs to come and, as the disruptions of the Challenger accident are put behind us, much new data emerging. As always, it is important to note that, although the core research is space plasma science must be through *in situ* measurements from space platforms, there are world-wide ancillary programs of ground-based observations of various kinds, using telescopes, radars, magnometer chains, riometers, etc. Furthermore, unique measurements are made by means of balloon-borne instrumentation and instruments carried on sub-orbital rocket flights.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

A. Galatic and Extragalactic Astronomy 1990-91

The past year has seen an important space astronomy mission launched within the NASA program, namely the second of the Great Observatories: the Gamma-Ray Observatory (GRO), which is now operating with enormous success in a near-Earth orbit. In spite of continued difficulties, high-quality observations continue to be undertaken with the Hubble Space Telescope (HST) and plans for its repair are being finalized. The German/United States/United Kingdom ROSAT has completed a very successful all-sky survey in the X-ray and EUV wavelength ranges and has commenced the pointed observation phase of the mission.

GRO is the second in NASA's Great Observatory series and its successful launch and operation in orbit, in April 1991, heralds the beginning of the next major phase in the discipline of gamma-ray astronomy. The Astro-1 payload, launched in December 1990 in a "shuttle attached" mode with an eight-day observing capability, was also operated successfully. The report of the NRC Astronomy and Astrophysics Survey Committee (the Bahcall Committee) was published and the recommendations contain a number of points that are relevant to space astronomy. Chief among these is the high priority accorded to SIRTF, a major IR mission which is the fourth in the Great Observatory series. In addition, the high priority given to the FUSE UV spectroscopy mission by the previous field committee was reaffirmed and the provision of a dedicated spacecraft recommended. Augmentation of the Explorer program was strongly recommended with special emphasis on Small Explorer mission. Difficulties with the composition of the FY 1992 NASA budget, and the consequent possibility of serious disruption to all the space science activities, marred what was otherwise a good year for the subject in the United States.

The European Space Agency's Horizon 2000 program is continuing successfully. Its position has been strengthened considerably by the conclusion of the work of the Pinkau Committee. Several recommendations of that body are being implemented with consequent improvements to the purchasing power of the program budget, while the member nations have effectively agreed to a further increase in the ESA mandatory science program budget. In spite of its original insertion into the wrong orbit, Hipparcos continues to operate extremely successfully and looks set to fulfill all of its mission aims. Plans for the repair of HST will, if implemented, enhance the value of the mission for the ESA community also. The preparation of the ISO IR mission continues towards a launch in 1993. Work on the XMM high throughput X-ray spectroscopy mission is gathering pace for a launch in late 1998, while more detailed studies of the heterodyne spectroscopy mission (FIRST) are well under way. Four candidate missions were identified for study for the next medium mission opportunity in the Horizon 2000 program. Two of these are in the space astronomy area. Integral is a powerful gamma-ray astronomy mission which would provide the ideal follow-up to the NASA GRO, while PRISMA is designed for stellar interior studies using highly accurate photometry supported by UV/EUV spectroscopy. The selection of ESA's next medium mission will take place in the second half of 1993.

The broadly based USSR program continues with the successful in-orbit operation of the Granat hard X-ray/gamma-ray astronomy mission. Preparations for the launch of the X-ray astronomy mission, Spectrum-X, continue, while the design and development of the Radioastron and UV astronomy missions are also under way. In spite of a difficult year for the USSR, in both political and economic terms, the program implementation is proceeding.

The Japanese Institute of Space and Astronautical Science (ISAS) is continuing its most successful program. With the launch of Yohkoh (Solar-A) in August 1991, the emphasis of the Space Astronomy program will turn to the preparation of Astro-D, a high throughput X-ray astronomy mission, for its 1993 launch. The development of a larger solid fuel launcher, the M5, is under way. This vehicle will be used to launch the long-baseline radio astronomy mission, VSOP, in 1995. The availability of a larger launcher will substantially enhance the capability of the ISAS program in the future.

The instrumentation involvements of other national programs are included below under the appropriate photon energy range.

1. Infrared Submillimeter and Radio Spectral Ranges

The analysis of the observations from the very successful NASA Cosmic Background Explorer (COBE) mission is continuing. The agreement of the spectral observations with what is expected from a theoretical black body spectrum, is remarkably good. A detailed analysis to search for small deviations from the black body spectral shape, which might have an important bearing on the early formation of galaxies, is under way. No anistropies have been discovered at a level of one part in 100,000.

The SOFIA project to construct a 2.7 m sub-mm and far IR telescope for flight on a NASA aircraft is still under discussion by United States and German authorities. The telescope would be flown above most of the Earth's water vapor and should be instrumented to provide a very high spectral resolution for wavelengths in the 30 to 350 m range together with 2.5 arc sec diffraction limited imaging. This program is strongly supported by the Bahcall Committee and NASA's advisory committees, who urge a project start in 1993/4 with observations beginning in 1998.

Among major United States missions, the Space IR Telescope Facility (SIRTF) receives the strongest support of the Bahcall Committee. A cooled 0.9 m telescope equipped with IR arrays for imaging and moderate resolution spectroscopy would be used in the wavelength range 2 to 700 m, following up earlier work with the ESA ISO mission and undertaking new deep surveys at a higher level of sensitivity. A new start for this mission is likely to occur before 1995/96, with an earliest launch date in 2000.

The United States IR/sub-mm program in space also includes a sub-mm wave astronomy satellite which has been selected as the first in a series of small Explorer missions. With a launch currently planned for 1995, this satellite should be the forerunner of a series of 200 kg spacecraft which would provide rapid access to space for a broad range of scientific disciplines.

Within the ESA program, work continues on the Infrared Space Observatory (ISO) mission. Scheduled for launch in late 1993, the 0.6 m telescope, which is cooled to 4 K, will be equipped to observe in the wavelength range 2 to 200 m with a total of four instruments capable of imaging, photometric, polarimetric and high-resolution spectroscopic observations. During its 18-month lifetime, ISO will be used in an observatory mode to follow up the discoveries made with the very successful IRAS IR sky survey mission.

Beyond the turn of the century, the launch of ESA's third cornerstone mission in the Horizon 2000 program can be anticipated. One of the candidates is the Far IR Sub-mm Telescope or FIRST mission. Designed to explore the 50 to 1000 m spectral range, the mission will comprise a passively cooled telescope in the 4 m to 8 m aperture range with actively cooled high-resolution heterodyne spectrometers, far IR interferometers and photometers. The objectives of the mission include the physics of the interstellar medium and star formation, cosmological studies and properties of primitive solar system material through observations of comets.

Following the successful demonstration that space-based VLBI is possible, which was undertaken using the NASA TDRSS, interesting results can be expected from the first purpose-designed VLBI space missions. Using the larger M5 rocket which is currently being developed, Japan's ISAS plans the launch of a VLBI mission (VSOP) in 1995. The USSR is also planning the Radioastron mission for launch around the middle of the decade. An integral part of all space-based VLBI missions is the existing network of ground-based radio telescopes, the availability of which will be essential to the success of any space enterprise in the field.

2. Optical and Ultraviolet Spectral Ranges

The International Ultraviolet Explorer mission, which began in January 1978, is now in its 13th year of operation and is probably the most successful scientific satellite ever launched. The program is a joint one, involving NASA, ESA, and SERC of the United Kingdom. Low and high dispersion spectral observations are undertaken in the wavelength range 1150 to 3200 Å while the spacecraft's geosynchronous orbit ensures a high observing efficiency coupled with a unique ability to study variable phenomena. The maintenance of comprehensive data archives by the collaborating nations has greatly enhanced the value of the mission for astronomers worldwide. Operations are set to continue into 1992 and no immediate threat is foreseen to the continued orbital lifetime of the spacecraft.

The NASA Far Ultraviolet Explorer (FUSE) mission, which is designed to observe the high-wavelength resolution in the important 150 to 1200 Å range, bids fair to become a worthy successor to IUE. This spacecraft, which should be launched in the 1999-2000 interval, will offer in particular an improvement of 100,000 in sensitivity in the cosmologically important 900 to 1200 Å range over the Copernicus satellite, which carried out the only previous observations in this wavelength interval. This mission has been highly recommended by the Bahcall Committee as part of an augmented NASA Explorer program.

In December 1990, the NASA Space Shuttle carried the Astro-1 payload into orbit for an eight-day mission to observe in the 900 to 3200 Å range with a suite of three UV telescopes. A broad-band X-ray telescope of novel design was also flown to observe a range of galactic and extragalactic sources in the 0.3 to 10 keV energy interval. Although some operational difficulties were encountered, all of the telescopes observed a large number of sources. Data analysis is now in progress and the first results from this mission are extremely encouraging.

The German/United States/United Kingdom ROSAT mission has completed the first full survey of the Extreme UV sky in the wavelength range 60 to 500 Å. The survey was carried out using the United Kingdom-provided Wide Field Camera which has so far discovered 1000 EUV sources, compared to the 12 that were known to exist before this survey. Following the conclusion of the seven-month survey, the mission is being used as an observatory, with specific proposals for X-ray and EUV observations being awarded time on a competitive basis.

A further EUV survey will be undertaken by the NASA Extreme Ultraviolet Explorer (EUVE) mission which is now due for launch in 1992. This spacecraft also includes an EUV spectrometer which will carry out follow-up studies of a number of objects.

Orfeus is a 1m class UV telescope which will operate in the 500 to 1200 Å wavelength range. A joint project of NASA and Germany, the telescope will be mounted on the German Astrospas platform and deployed from the Shuttle cargo bay during the course of an 11-day mission. Instrumentation will include three UV spectrometers provided by groups from the University of Tübingen, the University of California at Berkeley and Princeton University. The ESA Hipparcos spacecraft, launched in August 1989, failed to achieve its planned geostationary orbit and remained instead in an elliptical transfer orbit. At first this looked likely to have a highly damaging effect on the aims of the mission which involved the measurement of positions, parallaxes and proper motions of some 120,000 stars with a precision of 2-3 milli arc seconds. However, thanks to the very considerable efforts of the ESA project team, the satellite is now being operated successfully in its present orbit. A catalog of 120,000 star positions has been compiled to an accuracy of 5 milli arc seconds and it is expected that continued operation over an extended three-year lifetime will permit almost all of the original mission aims to be achieved by the end of 1992.

NASA's Hubble Space Telescope (HST), launched in May 1990, was the first of the Great Observatory series of satellites. The difficulties caused by the error in figuring the telescope's primary mirror and consequent degradation of angular resolution are now well-known and understood. Notwithstanding these problems, a large number of uniquely important results have been achieved in both the imaging and spectroscopic fields. Two issues of the *Astrophysical Journal*, published during 1991, have illustrated the range and quality of the science that is being achieved with the mission. Plans are almost complete which involve the replacement in orbit of one of the instruments, the Wide Field Planetary Camera (WF/PC), with a version that will include corrective optics to restore the originally planned 0.1 arc second angular resolution. In addition, by replacing the high-speed photometer instrument with a system of corrective optics, it will be possible to restore the performance of the remaining three instruments, FOC, FOS and GHRS, to almost the original specification. It is hoped that a shuttle mission can be scheduled by NASA to undertake the repair late in 1993 or early in 1994.

3. X-Rays, Gamma-Rays and Cosmic Rays

A major event of the past year was the launch, in April 1991, of NASA's Gamma Ray Observatory (GRO), which is the second in the series of Great Observatory missions. The spacecraft includes four instruments: i) the Burst and Transient Source Experiment (BATSE), which operates in the range of 0.03-1.9 MeV to locate burst and transient sources with a precision of 1 in a large field of view; ii) the Oriented Scintillation Spectrometer Experiment (OSSE), which undertakes gamma-ray line observations and positions sources with 10 arc min accuracy in the range 0.1-10 MeV; iii) the Imaging Compton Telescope (COMPTEL), which positions sources to an accuracy of 8 arc min within a large field of view in the 1-30 MeV range; and, iv) the Energetic Gamma-Ray Experiment Telescope (EGRET), which is a spark chamber operating in the 20 MeV to 30 GeV range with an angular resolution of 10 arc min and a field of view of 0.6 sr. All of these are performing well and yielding exciting results. These include the discovery that 3C279 is a strong and variable gamma-ray source (EGRET), the observation around one gamma-ray burst per day (BATSE), the positioning of gamma-ray bursts with high precision jointly with Ulysses (COMPTEL) and detailed studies of the 0.511 MeV annihilation line from the galactic center region (OSSE). Thus it is already clear that the GRO will have a major impact in the field of gamma-ray astronomy.

The USSR's GRANAT mission continues to operate most effectively in a number of areas including further studies of the galactic 0.511 MeV annihilation line. It is clear that the overlap with the GRO mission will be of considerable value for the subject.

The Japanese Ginga X-ray Astronomy mission, which is close to reentry, has accomplished a great deal since its launch in 1987. Highlights include the monitoring of SN1987A, studies of the spectra of active galactic nuclei together with observations of X-ray emission lines from a range of galactic sources and from the galactic plane. The Astro-D mission , which is being undertaken jointly by ISAS and a number of United States groups, will employ a broad-band flux collector of high sensitivity on the 0.1 to 10 keV range. This spacecraft will be launched in 1993.

Preparations for the USSR's Spectrum-X mission are well advanced for launch in 1995. The spacecraft will be placed in a highly elliptical orbit for enhanced observing efficiency. It includes a wide range of X-ray instruments supplied by groups in the USSR, United Kingdom, Italy, Germany , United States, Finland and Switzerland.

The German/United States/United Kingdom incidence X-ray telescope of 1-2 arc sec angular resolution. This instrument, with focal plane equipment supplied by Germany and the United States, has completed the most sensitive sky survey yet carried out in the 0.1 to 2.5 keV energy range. So far, more than 60,000 sources have been found and the results of this work will lead to major advances in X-ray astronomy. Although troubled by difficulties with the spacecraft attitude control system, the mission is now operating extremely successfully in a pointed or observatory mode.

In the NASA X-ray Astronomy program, the Broad-Band X-Ray Telescope flown successfully on the Astro-1 shuttle mission has obtained a number of striking results in the extra-galactic area, in particular where new spectral observations of clusters of galaxies and active galactic nuclei have been carried out.

The X-ray Timing Explorer (XTE), which will comprise the largest area proportional counter array yet flown, is now likely to be launched on a dedicated spacecraft in 1996. With an array of scintillation detectors in addition to the X-ray proportional counters, the mission will concentrate on timing observations for variable sources in the energy range 0.5 to 200 keV. An all-sky monitor which can survey 80% of the sky in 30 minutes is also included.

The Advanced X-ray Astrophysics Facility (AXAF) will be the third NASA Great Observatory. Launched near the end of the century, it will provide the appropriate combination of sensitivity together with an angular resolution of about 1 arc second to follow-up the discoveries that are being made with ROSAT. The focal plane instruments include imaging and spectroscopic systems using CCD's, microchannel plates, transmission gratings and a novel cryogenic detection system -the X-ray microcalorimeter for high-resolution spectroscopy in the range above 2 keV.

Within the ESA program, the EXOSAT data archives have been established and are now being widely accessed both in Europe and in the United States. The deep orbit of the EXOSAT mission made it particularly valuable for studies of variable sources, and so the easy availability of the archived material is especially important for work in this area.

The X-ray Multi-Mirror mission (XMM) is the second cornerstone of the ESA Horizon 2000 program. It comprises three separately nested grazing incidence X-ray telescopes and offers nearly 20 times more collecting area than AXAF at 7 keV, with an angular resolution of better than 20 arc seconds. The mission will therefore emphasize high throughput X-ray spectroscopy and will thus complement the AXAF observatory. It is equipped with CCD's, reflection grating spectrometers and a separate 0.3 m optical telescope which will permit simultaneous observations to be undertaken from 1 to 10,000 Å.

In the space astronomy field, the selection process for the next ESA medium-scale mission of the Horizon 2000 program, which will take place in the latter part of 1993, will include the INTEGRAL gamma-ray and the PRISMA stellar photometry missions.

Work is continuing on the Italian SAX X-ray Astronomy mission, which includes groups from the Netherlands and from the ESA-ESTEC Center. The mission, which will operate in the 0.1 to 200 keV energy range, should be launched in 1993.

B. Solar Physics

The understanding of the Sun, which had made many important advances in the first half of this century, reached a temporary pause during the 1940's, having to a large extent exhausted the analysis possible from the limited access to the visible spectrum as seen through the Earth's atmosphere. With the advent of space rockets and the capture of V2 vehicles in 1946, the Sun became the first object for study in radio astronomy. From that day on, solar physics studies have been revitalized. Studies of the Sun have always remained in the forefront of innovative space research, and is today the most mature of all the space sciences.

Motivation for solar studies falls into three broad categories. As the nearest star and the only one for which the available spatial resolution is efficient and where access to the entire electromagnetic spectrum is unobscured, the Sun provides a unique point for the physics of stellar evolution, structure and activity. The second area concerns the Sun as a plasma laboratory. The possibility to observe the behavior of hot plasma, the fourth state of matter, in a near steady state, is not yet available on Earth. Solar studies contribute enormously to the exploration of MHD phenomena and the collision physics and spectroscopy of highly ionized atoms. The third area is that of solar-terrestrial relations. Emissions from the Sun dominate the Earth's environment and provide the physical properties exploited by all forms of life on the planet. This aspect, already crucial for understanding the balance of physical processes, gains importance with the increasing awareness of global change and the evolution of the environment produced by industrial development.

1. Solar Activity

In the past three decades the greatest advances in solar physics from space occurred in the domain of high- energy emissions such as UV, EUV, X and gamma-ray photons, charged particles and neutrons. In particular, the Solar Maximum Mission, in orbit from 1980 to 1989, through its coordinated studies over a wide range of radiations, has made very significant contributions to the understanding of flare phenomena. This emphasis on coordination will be a key element in many future projects. The space environment (free of atmospheric effects harmful to observation) has also greatly advanced certain visible light studies by coronagraphs, which have contributed to our understanding of the role of solar magnetic fields and of transient phenomena in the interplanetary medium. The combined observation of high energy emissions and magnetic field dynamics represents a key strategy for understanding the mechanism of solar flares and other transients. The recent launch of the satellite Yohkoh (Solar-A) is expected to lead to further important advances in our understanding.

2. The Quiet Solar Atmosphere

Since the "quiescent" solar chromosphere and corona have such high temperatures, they must be observed at shorter wavelengths in the UV and EUV. The main problem here is to understand the mechanism whereby a small fraction of the mechanical energy resident in the convective motion of the lower cooler photosphere is be transferred upwards to result in the heating of the corona and the acceleration of the solar wind. According to the laws of thermodynamics, this transport must be effected by non-thermal means since heat cannot be transported in the direction of a positive temperature gradient. Results from spaceborne instruments, such as those flown on Spacelab, rocket flights and other missions, with the invaluable cooperation from ground-based observations, have clarified a number of issues. We now have a picture of the three-dimensional structure of temperature and density, as well as the importance of continuous fine scale dynamic effects in the solar plasma and in the related magnetic field structures. The scale of the participating structures ranges from the limit of present-day telescopes (a few hundred kilometers on the solar surface) to large-scale unipolar regions called coronal holes. The observations demonstrate clearly the critical role of small-scale magnetic field structures in the transport process. Some of the previously proposed transport mechanisms can now be excluded, and there are some very positive pointers to the correct interpretation. Theoretical models based on wave transport or stochastic processes may be equivalent in the end, since any wave interpretation must involve extreme nonlinear amplitudes.

3. The Solar Interior

The techniques of space research are now being brought to bear on the understanding of the structure and dynamics of the solar interior and convection zone, in exploiting the new field of helioseismology. This field, developed over the past 20 years using observations from the ground, studies the modes of vibration of the global Sun, and interprets them in terms of the internal physical properties. Making observations in space removes the two obvious limitations of the day/night eclipsing and the atmospheric degradation. In particular, vehicles which orbit far from the Earth offer the possibility of long periods of uninterrupted solar viewing. The first space observations in a near-Earth orbit were obtained from the SMM satellite. More recently, while *en route* to the planet Mars, the Soviet Phobos spacecraft provided continuous data over a period of many months. Preliminary analysis of the Iphir experiment on Phobos shows very fine detail on the 5-minute global p-mode spectrum, which throws important light on the excitation mechanism for the modes. Three ambitious experiments are planned for the SOHO mission. These observations will help resolve the questions posed by the enigmatic low solar neutrino flux, as well as the internal differential rotation, convection and the generation of the solar magnetic fields.

4. The Solar Interplanetary Connection

Studies of the corona from space have shown the importance of the so-called "coronal holes", large areas of the solar surface with well defined boundaries, in which the corona has a much lower density. It is now accepted that these areas are those with an open field structure connected directly to interplanetary space. They are the major source of the steady solar wind and their understanding is thus crucial for the problem of solar (and stellar) mass loss and, ultimately, for stellar evolution. Their relation to the solar wind has so far been studied only in the ecliptic plane. With Ulysses, it will be possible to examine the role of the polar coronal holes, which it is thought could show a significantly larger wind flux.

5. Recent and Future Missions and Programs

There are now two major thrusts in the new missions currently planned. The first covers the study of activity during the next solar maximum in cycle 22 with missions such as Yohkoh, balloon projects and the Flares 22. The second relates to the quiet solar corona and its interaction with the interplanetary medium, with the missions Ulysses, Wind, Coronas and SOHO. In addition, opportunities will be exploited to pursue the techniques of helioseismology (SOHO), as well as to take advantage of the solar observing capabilities of certain astronomical missions (Sigma and GRO).

6. Yohkoh

The Solar A mission, launched by Japan in August 1991, carries a complement of instruments to monitor energetic flare phenomena and the evolution of coronal magnetic structures. This is the only satellite totally devoted to solar observations during the current maximum. Its payload includes a high resolution soft X-ray telescope provided by the United States and a Bragg crystal spectrometer developed jointly by experimenters in the United Kingdom and United States. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing a much better sensitivity, energy range, and spectral resolution than imaging detectors previously flown aboard the SMM and Hinotori missions. Higher energy X-rays, gamma rays and neutrons will also be monitored by Solar A instruments. Significant improvements in temporal resolution, eg. 2 seconds in gamma ray spectra as compared to the 16 seconds of the SMM spectrometer, should provide new insights into the understanding of the particle acceleration and interaction processes in flares. All instruments appear to be functioning correctly.

7. Ulysses

Ulysses, formally known as the International Solar Polar Mission, was launched in October 1990 on its long journey to study the solar poles from outside of the ecliptic plane. It will use the gravitational field of Jupiter to deflect its trajectory so as to pass over both solar poles at a distance of around 1 AU. Ulysses carries a variety of particle detectors for studying the solar wind *in situ*, as well as two small scintillation detectors for observing X-rays from 15 to 150 keV. It is thought that much of the solar wind seen in the ecliptic plane at 1 AU arises from the solar polar regions. It is therefore highly probable that the wind that we know at present is not typical of the general solar wind, which might be quite different perpendicular to the ecliptic plane. Ulysses thus offers the possibility of advancing significantly the understanding of solar evolution and mass loss.

8. Sigma

Sigma is a French experiment aboard the Soviet Granat satellite. Although its main objective is to map the gamma-ray sky and locate non-solar sources, its cosmic gamma-ray burst detectors are also obtaining flare spectra up to energies of 100 MeV. Sigma is also designed to make high sensitivity and temporal resolution observations of flare emission in the 50 keV to 7.5 MeV range.

9. Wind

The Wind spacecraft, a component of the Global Geospace System (GGS), which is part of the International Solar-Terrestrial Program (ISTP), will carry a high-purity germanium detector of solar flares and cosmic gamma-ray bursts in the 25 keV to 8MeV energy range. In addition to gathering information on gamma-ray lines due to accelerated particles in large events, the spectrometer will provide nearly continuous monitoring of hard X-ray emission from flares, with spectral resolution superior to that of the SMM spacecraft.

10. Gamma-Ray Observatory

The Gamma-Ray Observatory (GRO) is NASA'S major mission in high-energy astrophysics. GRO, which was launched early in 1991, carries four large instruments with the objective of obtaining comprehensive observations of cosmic sources in the 20keV to 30GeV energy range. GRO is also well-suited for observing solar radiation - gamma-ray and accelerated neutrons - which are evidence of the most energetic processes occurring in flares. Of the four instruments, the Burst and Transient Source Experiment (BATSE) has the greatest capability for flare observations, due to its large sensitive area. It should provide extensive high temporal resolution observations of flare emission in the 50 to 1000 keV energy range. Observations of the nuclear line region of the spectrum will be provided by two other instruments, the Oriented Scintillation Spectrometer Experiment (OSSE) and the Imaging Compton Camera (COMPTEL), while the Energetic Gamma-Ray Experiment and the Telescope (EGRET), which covers the 20 LeV to 30 GeV portion of the spectrum, will probe the most energetic phenomena on the Sun.

11. Coronas

Coronas is a series of Soviet satellites planned for launch starting in 1992 and aimed at observing the solar atmosphere from near-Earth orbit, solar activity, and magnetospheric solar effects. They will carry a number of instruments developed by Soviet groups in collaboration with groups in many other countries. Current plans include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as studies in helioseismology.

12. Balloon Programs

Several countries, including China and the United States, have plans to carry out balloon observations with instruments dedicated to flare physics. Many of these will be carried out in long-duration balloon flights. In the case of the United States, the Max 91 program includes the flight of the High Resolution Gamma-Ray and Hard X-Ray Spectrometer (HIREGS), which will be able to investigate the region 15 keV to 20 MeV with high spectral resolution.

13. The International Flares 22 Project

In an international effort similar to the successful Solar Maximum Year (SMY) program of the early 80's, the world-wide solar community will join forces once again in a program of flare research at the maximum of cycle 22. Flares 22 will be an integral part of the Solar

Terrestrial Energy Program (STEP), sponsored by the Scientific Committee on Solar Terrestrial Physics (SCOSTEP). Research on active phenomena will require the analysis of data from many individual spacecraft and balloon experiments, as well as from highly improved ground-based observatories. Flares 22 will focus international attention and collaboration on the analyses of these data and on subsequent theoretical work.

14. SOHO

ESA, in collaboration with NASA, is developing the Solar and Heliospheric Observatory (SOHO), due to be launched in 1995. It will orbit the L1 Lagrangian point at 1.5 million kilometers from the Earth, a location that offers continuous viewing of the Sun and is an ideal site for *in situ* wind measurements and helioseismology. Soho is the most ambitious solar project developed so far. Its instruments will probe the entire Sun, from its center by means of helioseismology, its outer atmosphere by remote sensing visible and UV observations, and the wind at 1 AU by *in situ* studies. Instruments are being provided by European and United States consortia. The helioseismology instruments include GOLF (Global Oscillations at Low Frequencies), VIRGO (Variability of Solar Irradiance) and MDI:SOI (Michelson Doppler Imager). These will measure global oscillations, the solar radiative output and surface magnetic fields. A detailed study of the solar atmosphere from the chromosphere to the corona is the subject of CDS (Coronal Diagnostic Spectrometer), SUMER (Solar Ultraviolet Emitted Radiation) and EIT (EUV Imaging Telescope). The higher corona will be observed by UVCS (Ultraviolet Coronograph Spectrometer) and LASCO (white light and spectrometric coronograph). Combined, these instruments can measure the temperature, density, composition and velocity of solar plasma at various heights, with the aim of deriving the balance of energy and mass up to a height of 30 solar radii. SWAN (Solar Wind Anisotropies), CELIAS (Charge Element and Isotope Analysis), COSTEP (Comprehensive Suprathermal and Energy Particle Analyzer) and ERNE (Energetic and Relativistic Nuclei and Electron Experiment) will probe many aspects of the solar wind. These instruments will study the wind structures and relate them to coronal structures and dynamics.

15. Projects for Future Missions

A number of projects are under study in view of the obvious need to ensure further progress of solar physics in the next century. OSL, with a minimum lifetime of three years, is an observatory-type mission in a polar orbit, which would provide continuous data in white light, UV, EUV images and spectra, with 0.1 arc sec resolution. It includes a 1 meter telescope feeding a number of focal plane instruments. Its new start has, however, been delayed substantially by recent planning decisions. Plans to extend the measurement of global oscillations in intensity to solar-type stars are also under way. A preliminary experiment is planned for the Soviet Mars-94 mission, while a more extensive program is included in the ESA study PRISMA. These ideas, amongst others could serve to ensure a bright future for solar physics at the start of the next millennium.

VI. LIFE SCIENCES AND SPACE RESEARCH

A. Gravitational Biology

1. Space Medicine

During the reporting period, human expeditions of long duration were continued in space on board the orbital complex Mir. Besides a complex scientific flight program (such as fundamental and applied research in the field of gravitational biology, physiology and medicine) the main goal is to maintain good health and high work capacity of the crew. This endeavor includes the optimization of crew habitats, the improvement of the life support systems and measures to counteract the impact on the human body of a multi-month spaceflight, as well as improvements in the reliability of radiation safety systems during space missions. The ultimate goal is to preserve the functional capacity of the crew throughout long-term missions, which include periods of extra-vehicular activity. The efficacity of the medical support system has also been increased to reduce re-adaptional disorders in the human body when returning to Earth conditions. The results provide valuable information necessary for planning human expeditions to Mars.

Within the United States Space Shuttle program, the emphasis is on manned missions and the associated research in human physiology. In rticular, in preparing the Space Station scenario, the United States are putting emphasis on the studies of the human body's reaction to 16-20 day missions in weightlessness. In Europe, a series of Columbus precursor flights are planned, using the Spacelab and EURECA facilities. For the upcoming German Spacelab mission D2, the Anthrorack will provide an intensive investigation program on human adaptation to spaceflight conditions.

2. Space Biology

On Mir, biological studies on higher plants (e.g. Greenhouse-Svet-Experiment) and on small animals (e.g. development and life span of the Japanese quail) carried out with international participation, help answer vital issues of gravitational biology. They also provide important basic information for the creation of ecological life support systems for future generations of autonomous space complexes and of interplanetary manned missions.

The United States Spacelab mission SLS-1 which will be performed in international cooperation includes studies at the molecular and cellular levels, as well as studies on tissues, plants and animals (including mammals).

The Soviet Biocosmos (Cosmos 2044, launched in September 1989) which contained primates, rodents, plants, tissues, bacteria, etc. yielded a wealth of information on living systems' reaction to both weightlessness and to cosmic radiation. The experimental data were presented in St. Petersburg at an international symposium in August 1991. This mission, probably larger than any previous, involved widespread international cooperation including Western European countries and the United States. Some 200 scientists participated, of whom many actively supported the research on this mission.

B. Radiation Biology

Proton radiation predominates on missions in low-Earth orbit. In deep space, not only protons, but also heavy charged particles contribute to the radiation environment. The radiobiology of the heavy charged particles is of particular concern. There is dense ionization along the particle track, and in the case of the higher Z particles, the track may traverse a considerable number of cells. The high density of the ionization along the track results in high radiobiological phenomena for certain effects. It is therefore essential to understand both the early and the late effects of heavy charged particles in order to estimate the risks of prolonged sojourns in space.

Not only the effects of radiation in space have to be understood, but also the effects of microgravity. The question of whether or not radiation and microgravity interact is an important one, which can only be answered by studies in space. These problems were discussed during the NATO Advanced Study Institute in October 1991, in Armaçoa de Pera, Portugal.

1. Ground Research

There are a limited number of particle accelerators suitable for studying the effect of heavy energy ions and high Z in the worker, and research is concentrated at the GSI accelerator at Darmstadt, Germany, at the Joint Institute of Nuclear Research at Dubna, Russian Federation, and at the Bevalac at Berkeley, California, United States. Studies have been carried out on high energy heavy ion propagation, in order to determine the radiation environment in space vehicles and for the design of shielding. An important characteristic of heavy charged particles is fragmentation caused, for example, by the vehicle shielding. The effect of fragmentation, the interactions of particles and matter and the production of secondary particles are all under study. The progress made so far in the definition of the possible radiation environments within space vehicles will help the designing of adequate shielding.

The effects of exposure to HZE particles, which are currently being studied, include damage to DNA, mutation, malignant transformation, cataract induction, changes in behavior and biochemical activities in the brain, and life shortening. It has been shown that HZE particles are more effective than other radiations in the production of many biological effects.

2. Research in Space

A considerable amount of dosimetry and testing of methods and equipment has been carried out in the last year, in the course of United States and USSR missions. A portable tissue equivalent proportional counter spectrometer has been introduced and tested. A collaborative study of radiation effects was performed on the Cosmos 2004 Biosatellite system, involving scientists from Czechoslovakia, France, Germany, The Netherlands, United States and the USSR.

More precise measurements of the dose and energy and LET spectra than previously available have been obtained for low Earth orbit missions from work in a number of countries.

On board the "Long Duration Exposure Facility" of NASA, different biological samples, such as spores, seeds and shrimp cysts, were exposed to a high influx of cosmic radiation for nearly 6 years. A series of experiments of the Biostack type, allowing localization of the trajectory of single particles in biological layers, have provided basic information on the impact of radiation in space on biological integrity during long-term missions.

The possibility of an interaction between radiation and microgravity has long been recognized. However, such interaction has not yet been determined quantitatively with enough precision to understand the potential risks. Recent work indicated that the combined exposure to HZE particles and microgravity act synergistically on eggs of a simple organism and can result in developmental anomalies. More research is required to establish the combined effects of radiation and microgravity on various cell systems and cellular functions.

C. Planetary Biology and the Origins of Life

1. Planetary Biology

After the evaluation of the data from the Giotto and Vega 1 & 2 missions, interest is now focused on the Mars 94 mission. Preliminary objectives currently under study include sample analysis which may supply significant data relevant to the organic chemistry of Mars, and perhaps even to its paleobiochemistry. The selection of landing sites is of crucial interest also to the exobiologist. Chances of finding extant life at the Mars surface are, however, extremely small, but providing that the origin and evolution of life proceeded as on Earth, traces of active life could be found deep in Martian permafrost or in the neighborhood of hydrothermal veins. Experimental research in planetary biology therefore focuses on the following questions: What are the limiting conditions for active life and for dormant life? Are the Antarctic ecosystems (eg. the cryptoendolithic systems) a model for an ecosystem on early Mars? Are there chances for a (spontaneous) interplanetary transfer of life between Earth and Mars?

Among other planetary missions under preparation, the joint ESA/NASA Cassini mission to Saturn and to its largest satellite Titan is of special importance. The Cassini mission, with its Huygens probe, will offer a unique opportunity for *in situ* studies of the complex organic chemistry on Titan, an extraterrestrial organic chemistry in the absence of liquid water.

The SETI (Search for Extraterrestrial Intelligence) program was initiated by NASA to search for signs of life beyond the Earth.

2. Origins of Life

Research has continued to focus on a number of issues: Is there a prebiotic pathway to nucleic acids? Were the first enzymes nucleic acids? Can nucleic acids replicate themselves and synthesize peptide bonds without the help of proteins? How and when did chiralic systems (optical activity) originate? How did early bioenergetic pathways evolve? How did genetic information originate?

The first of these has been a source of concern to evolutionary chemists for decades, because a prebiotic (that is, abiotic) evolution of nucleotides and nucleic acids has thus far to be questioned for at least two reasons: firstly, a plausible prebiotic pathway to ribose or 2-deoxyribose (yielding substantial amounts of these sugars) could not be established; and secondly, a route toward a stereoselective synthesis of first replicable polynucleotides is not known.

An interesting approach to the resolution of the first problem has recently been achieved by a Swiss laboratory which has demonstrated an abiotic pathway from formaldehyde, HCN and acetronile (all interstellar molecules, HCN and acetonitrile are also established components of the atmosphere of the Saturn satellite Titan) to a variety of racemic sugar phosphates including hexose-trisphosphates and ribose-2, 4-bisphosphate (involving the intermediate formation of glycolaldehyde-phosphate).

In view of the preferential formation of hexose-phosphates, the Swiss group has also suggested that hexose-nucleic acids may have preceded pentose-nucleic acids. New impulses are likely to result from this approach.

3. Experiments in Space

The use of free-flying satellites for exobiological research in space has been studied by ESA. The following issues have been identified for consideration: the relevance of extraterrestrial molecules to the emergence of life on Earth or on any other planet; the role of solar UV radiation in evolutionary processes related to life; the chances and limits of life being transported from one body of our solar system to another, or beyond; and, exobiological phenomena in aerosols and clouds.

The preparation of the experiments of the Exobiology Radiation Assembly (ERA) of the European Retrievable Carrier (EURECA), to be launched in 1991, is being completed. The program includes investigations on the formation, stability and destruction of organic molecules and polymers, as well as on the biological responses to solar UV in space, such as genetic changes of viruses, bacterial and fungal spores or nematodes.

D. Natural and Artificial Ecosystems

1. Biospherics

Theoretical models and remote sensing techniques are used to elucidate the interaction of the biosphere with its environment on Earth (atmosphere, hydrosphere, lithosphere). Remote sensing technology has been applied to a variety of studies on wild fires, malaria and other vector borne diseases, biomass estimation, pollution control and the ozone problem. Experiments carried out in tropical rain-forests have examined nutrient cycling, particularly nitrogen. Forest-level estimations of photosynthesis based on air-borne experiments on CO_2 have been undertaken and appear promising. Carbon dioxide cycling models have been expanded to include effects of continental margins, seasonality effects based on temperature, and exchange from the air-sea interface.

2. Controlled Ecological Life-Support Systems

During the reporting period, advances have been made in the development of bioregenerative life support systems that make use of growing plants, supported directly or indirectly by sunlight and capable of using a space crew's carbon dioxide to produce food, oxygen and potable water. Various aspects of this approach to life support are currently under investigation by scientists in the United States, Japan, USSR, France, Germany and Canada. Pilot experiments are being planned for the forthcoming space missions by the United States and USSR.

Recent work has begun to address issues of the total spacecraft ecological system, which includes humans, plants; animals, and microbial organisms. The need for artificial ecosystems on extra-terrestrial bases, such as the Moon or Mars, is another topic of intensive investigation.

VII. FLUID AND MATERIALS SCIENCES, MICROGRAVITY SCIENCE AND SPACE APPLICATIONS

Microgravity science and applications include: basic and applied research in fundamental science (relativity, condensed matter physics, fluid dynamics and transport phenomena, combustion science); materials science (electronic and photonic materials, metals and alloys, glasses and ceramics) and biotechnology (protein crystal growth, separation science, cell science) studied in the absence of gravity. Experiments conducted under these conditions can clarify the roles of factors normally masked by, or competing with, gravity-induced phenomena (i.e. sedimentation, hydrostatic pressure, convection and buoyancy) in complex physical processes. The elimination of hydrostatic pressure in the absence of gravity, for example, may also be used to make ultra-precise critical fluid measurements which are not possible on Earth, because of the inhomogeneities in the thermodynamic state induced by the pressure gradient.

The resulting contributions to science may be applied to advance the state of both Earth- and space-based technology. The quiescent space environment may also be exploited to process selected materials in unique ways. For example, both organic and protein crystals of a composition, size, quality and uniformity unattainable on Earth may be obtainable in space. These and other space-processed materials may have important applications, e.g. in the development of new pharmaceutical products and advanced engineering and electronic materials.

A. Fundamental Science Research

Fundamental science research includes studies of the gravitational theory, the behavior of fluid transport phenomena and combustion science in microgravity. A fundamental assumption in Einstein's Theory of Relativity is the equivalence of gravitational and inertial mass. NASA is sponsoring research that may lead to an ultra-high precision equivalence principle experiment which would extend the accuracy of these experiments to one part in 10^{17}. A critical piece of test hardware was developed to measure the test mass position and to evaluate the dynamic behavior of the test mass in the apparatus' magnetic bearing. A major study detailing the science requirements and including a comprehensive error analysis was completed. The French microgravity program is investigating low-gravity optical cooling of atomic vapors, to produce a microgravity atomic "molasses" of cooled atoms. Follow-on studies in the PHARAO project will investigate the application of this approach to a new generation of on-orbit atomic clocks with greatly enhanced frequency stability and precision. Such instruments will, in turn, permit even more stringent tests of the gravitational equivalence principle.

Ground-based research in fluid physics and condensed matter science aims at understanding critical point behavior, in general, and in microgravity helium physics, of the "Lambda Point" in particular. In one study, investigators are pursuing the measurement of fluid viscosity near the critical point. This research directly supports the Lambda Point flight experiment. A complete set of all useful critical point viscosity data for single component fluids have been collected under 1 g conditions. The analysis of these data will enable further refinements of the requirements for a space-based experiment to complement the Critical Fluid Light Scattering Experiment already under development. Another activity involves the investigation of critical transport properties and fluid and interfacial transport properties of liquid helium under low gravity. Fluid and interfacial transport phenomena are central to a large number of physical, chemical and biological processes. As gravity is reduced in a liquid-gas system, interfacial tension forces begin to control the shape, location, and stability of the liquid-gas interface. The familiar, flat liquid surface meniscus experienced on Earth can be dramatically altered under microgravity conditions and can be driven into what are, in some cases, unpredictable motions, shapes and locations. Theoretical studies and experimental hardware have supported ground-based testing of the theory.

Despite many years of normal gravity study, the mechanisms of flammability, stability, and ignition limits in premixed gas combustion are not well understood, due, in part, to the influence of gravitationally induced buoyancy. The emphasis here of microgravity study is on determining what physico-chemical processes are responsible for each type of flame front limit behavior in the near-absence of buoyancy. On Earth, gravity causes hot reacting gases produced by flames to rise in the same way oil floats on water or helium balloons rise. Buoyant convection brings fresh oxygen to meet fuel vapor from the surface. The spread rate of the flame is directly affected by the rate at which the fuel and oxygen are mixed with the help of buoyant convection. In space, the absence of gravity eliminates buoyant convection. The supply of oxygen to the flame is reduced dramatically to only the oxygen the flame encounters as it moves along the solid surface. The Solid Surface Combustion Experiment examines the fundamental mechanisms of flame spread in the virtual convection-free heat transfer of near-Earth orbit. This experiment has yielded eight data points on spreading velocities at varying thicknesses and atmospheric composition. Data obtained to date in space has contributed to formulating better theoretical models of radiative heat transfer in solid fuel combustion.

B. Research in Materials Science

Research in materials science includes the processing of electronic and photonic materials; metals and alloys and composites; glasses, ceramics, and polymers. Containerless processing of pure refractory metals and niobium-based binary alloys have been studied. Solidification velocities of undercooled pure niobium were studied under microgravity conditions. Because experimental results did not correlate well with prediction from established theory, additional tests are under way.

Directional solidification of metals and alloys will be studied on six forthcoming flights of the United States Microgravity Payload (USMP), in a joint effort by NASA and the French research groups CNES/CEA using the Mephisto apparatus. Mephisto will provide microgravity conditions for monitoring the speed, shape, and temperature of a solidifying crystal/melt interface. Comparison with ground-based data will provide the first reliable data on kinetic conditions at a convection-free solidification interface. The solidification in a metal alloy casting process is even more complex than the growth of single crystals, and usually not as well controlled because of multidimensional heat transfer. Useful alloys often have multiple elemental components, each of which has a different freezing temperature range and chemical segregation coefficient. In addition to the microsegregation and macrosegregation effects for these components, multiphase reactions can occur when a liquid alloy transforms into two distinct solids, or phase separates into two immiscible liquids. Early microgravity experiments revealed the influence of strong interfacial effects which play a major role in such phase separation.

NASA began work in 1991 with the Sandia National Laboratories on the development of the Mechanics of Granular Materials (MGM) Experiment. Granular materials, and in particular geologic deposits in their *in situ* state, are in most cases partially or completely saturated. In such states, the interactions between solid particles and interstitial liquids which, in turn, are functions of external loading and drainage conditions during loading, can result in many catastrophic events from a geotechnical engineering point of view, which may involve the loss of life and property and the alteration of natural resources. The experiment entails a test series on granular materials in dry, partially saturated, and fully saturated states. In 1992, France and the USSR will collaborate bilaterally in the Alice experiment aboard Mir station, studying the influence of random macroscopic media on fluids near their critical point.

Finally, in June 1991, a gallium arsenide (GaAs) III-V semiconducting crystal was successfully grown under microgravity conditions by GT&E Corporation. This crystal was grown by seeded directional freezing from the melt in a small, battery-powered crystal growth furnace, which was integrated as a GAS can experiment launched on STS-40. The GaAs crystal, which appears to be quite homogeneous, was grown, after partial remelt, at a steady rate of 5 micrometers/sec, and appears to be the first such crystal grown entirely without free surfaces, using a novel piston-driven pressure containment system within the crucible. Samples have been cut from the space-grown crystal and distributed for detailed synchrotron topographic and defect analysis, and for complete electronic characterization, which will be provided by the sponsors of this research, including NASA, GT&E Corp., and the United States Air Force.

C. Research in Biotechnology

The benefits of the microgravity environment to biotechnology research are currently being investigated. Ground-based research on growing various protein crystals in preparation for a flight experiment has resulted in the growth of crystals of human serum albumin (HSA). As a result, researchers were able to determine the three-dimensional molecular structure of this protein to a resolution of 6 Å. This finding represents a scientific breakthrough in the area of rational drug design, because the HSA molecule is important to the transport of many biological and pharmaceutical molecules in the bloodstream. Researchers have continued to refine the analysis and testing of electrohydrodynamic effects of soluble molecules at varying concentrations with fixed conductivity and at various pH, ionic strengths, and sample-to buffer conductivity ratios. State-of-the-art bioreactors are being used to simulate some aspects of microgravity in order to obtain three-dimensional tissues rather than a flat sheet of cells that is typically obtained using traditional culture techniques. Results to date indicate that some human primary cell cultures (e.g. colon epithelial cells and lymphocytes) can be grown in greater quantities in bioreactors than in traditional cell culturing equipment. Tissues formed during the culturing of human tumor cells have produced detectable factors not previously identified.

The Microgravity Science and Applications program is now entering a phase of highly active spaceflight activity. Two more protein crystal growth experiments and the first combustion science experiments have flown in space and were highly successful. The year 1992 will witness the launch of the first of the International Microgravity Laboratory (IML) series of flights. IML will carry multiple flight experiment payloads built by investigators from both the United States and its international partners. Also, the first flight of the United States Microgravity Laboratory, to be carried aboard Spacelab in 1992, represents the highest priority near-term flight opportunity for United States microgravity experiments. Four major experiments, including the Drop Physics Module, the Crystal Growth Furnace and Surface Tension Driven Convection Experiment, and the Solid Surface Combustion Experiment, are scheduled for that mission. Other missions will include the Spacelab-J and the United States Microgravity Payload (USMP) flights, which are unmanned, semi-autonomous microgravity experiments sited in the orbiter bay of the STS.

Opportunities for space-based research into the fundamental sciences, materials sciences and biotechnology have prompted innovative and important experiment proposals from the international scientific community. The potential rewards of the microgravity program include a deepening of our understanding of the physical processes in our environment, advances in technology in numerous engineering disciplines, and improvements in the quality of life on Earth. In addition, the knowledge gained from space-based microgravity research may lead to important commercial applications. Interest in new areas of opportunity for microgravity science, such as capillary wave turbulence, drop dynamics and chaotic phenomena, metal combustion, spray combustion, and combustion synthesis of ceramic-metal composites, are a strong indication of the continued vigor of the international microgravity sciences program. Three NASA research announcements (NRA's) have been released recently in the areas of biotechnology, fluid dynamics and transport phenomena, and materials science, which will provide encouragement for new and interesting areas of research to be pursued in the microgravity environment.

VIII. SATELLITE DYNAMICS

A. New Techniques for Satellite Positions and Orbit Determination

On-board systems for signal reception and processing permit determination of the satellite's position and calculation in real time of orbital elements. System DORIS is based on the network of ground stations covering the entire Earth and the Doppler effect recordings by the satellite receiver. Other possibilities are applications of signals from the GPS navigation system and the TDRS geostationary satellites. These methods enable the full coverage of the satellite trajectory by observations enhancing the accuracy of the orbital resolution.

B. New Geopotential Models

New models of the Earth's gravity field based on analysis of satellite orbits have been published with the resolution 360*360 and very high accuracy. This accuracy enables investigation of temporal changes of the geopotential. Secular change is found in the J2 term probably reflecting the postglacial rebound in the Northern hemisphere.

C. Application of GPS to Sea Level Changes Monitoring

A world-wide program has been started to investigate changes in the water level of the global ocean. Tide gauge stations have to be linked in one unified system by means of GPS satellite signals. High precision GPS orbits will be used in determining the expected change.

D. Gravity Fields of Planets and Moons in the Solar System

New gravity field models for Mars and Venus are being published, with higher resolution and accuracy based on orbital data from earlier missions. The Magellan mission provided new radar data enabling compilation of the topography model for Venus. Important results have also been obtained from fly-bys about planetary gravity. Jupiter, Saturn, Uranus and Neptune have improved gravity field models thanks to the Viking mission.

IX. SCIENTIFIC BALLOONING

The major activities in scientific ballooning are still to be found in the fields of balloon film technology and of the problems related to long-duration flights with often large and heavy payloads.

There is a rather intense activity in the development of new balloon films, as a result of the failures reported some years ago. The problems were analyzed and solutions were found. Not only have new products appeared on the market, but theoretical analyses and design studies have been performed.

Continuous growth and the complexity of balloon payloads have led to a need for long-duration flights to compensate for the high costs involved. Groups within NASA, as well as in Japan and France, are very active in this respect, and are carrying out programs of vital interest to the science community. Flights and experiments are foreseen which, while less numerous, are more complex and, therefore, more expensive. There are good prospects for scientific ballooning, in particular for long-duration and multiple simultaneous flights.

The importance of international cooperation is being stressed by the upcoming International Space Year. Flights, without recovery, are being considered over Antarctica, with facilities made available by the Soviet Union, Japan and others, as are transoceanic ones (trans-Pacific). The future of scientific ballooning depends on the development of long-duration flights. The goal of France and the United States to achieve flights of more than two months duration with inexpensive systems is in sight. Circumpolar flights in the Southern hemisphere pose major problems of a political character with regard to overflight permissions. The Arctic is potentially also a very important area.

Efforts in instrumentation are dominated by the astrophysical sciences. Their payloads are most involved and require thorough planning. X-ray, gamma-ray, infrared and ultraviolet radiation detectors are the standard equipment, and remain useful for many campaigns. Activities are also being developed in the field of atmospheric chemistry (aerosols, nitric acid, etc.), some of which use mass spectrometers.

Some interesting proposals for scientific ballooning are being made. Among these are heavy (two ton) instrumentation for infrared astronomy with the first flight to occur in 1992 or 1993 from Japan or Australia, and atmospheric research on ozone in the Southern hemisphere, in the South polar vortex using super-pressure balloons. The flight duration will be several weeks, with payloads for measuring trace constituents weighing about 50 kg. A test campaign launched from Argentina is planned for 1993, and the vortex campaign itself will involve one hundred balloons.

Another new application for balloons is appearing in the field of planetary research. The planet Venus was the target of a Soviet space mission, which used balloons for the exploration of its planetary atmosphere. Future interplanetary space activities will focus on planet Mars and some interesting balloon experiments are being developed in this context.

India is quite active in scientific ballooning, launching 70 balloons annually, most of them carrying xenon-filled and Phoswich detectors. One or two flights each year are devoted to infrared astronomy. India is pursuing this activity and developing some new experiments, and upholds international standards in balloon and payload technology.

Increasing interest is being shown for investigations in the fields of solar-terrestrial and magnetospheric physics, specifically in relation to satellites to be launched in the 1990's. In particular, at a workshop in Spitsbergen dedicated to planning ground-based, rocket and balloon studies in conjunction with the Cluster satellites, the technical aspects of possible balloon campaigns were discussed. Campaigns involving a number of small balloon payloads, which can be rather easily launched, were seen as a valuable supplement to the ground-based campaigns being planned in the Svalbard region.

The fields of interest during the last two years can be summarized as follows. Balloon design, materials science and performance analysis for balloons are the necessary basis for ballooning. The considerable complexity of national and international campaigns requires close international cooperation both to solve political issues, such as overflight permissions, and to handle more technical problems, such as those related to communications and positioning, long-duration flight, etc.

In conclusion, balloon experiments in the stratosphere and planetary atmospheres provide a well-established means for carrying out scientific research. The development of new balloon systems and materials goes hand in hand with the scientific efforts. From the geographical point of view, most of the activities are taking place in Japan, the United States, France, India and the Soviet Union, but there is continued interest in other countries as well.

X. SPACE RESEARCH IN DEVELOPING COUNTRIES

The COSPAR Panel on Space Research in Developing Countries (PSRDC) was reconstituted in 1983. The Panel receives modest financial support for its activities from the ICSU-UNESCO Subvention.

In 1990, a considerable effort was made by the Panel to set up arrangements for promoting the active participation of scientists from developing countries in the 28th COSPAR Plenary Meeting, which was held in The Hague, Netherlands. Recognizing that the equatorial electrojet is a phenomenon which is actively studied in many countries, the Panel organized a two-day scientific meeting under the title, "The Equatorial Electrojet and Related Phenomena". With COSPAR and the United Nations, the Panel provided travel support to a number of active scientists from developing countries, enabling them to attend the various scientific sessions of the Plenary Meeting.

In 1990 and 1991, the Panel continued supporting scientists from developing countries and encouraging them to attend conferences and symposia on space research, providing partial travel support for attending training courses in space research.

In 1991, the Panel expressed its interest in the symposium on "Global Change and Relevant Space Observations", which is being organized by COSPAR for the upcoming Plenary Meeting in Washington, DC. Accordingly, a session at the symposium will be reserved for "The Use of

Satellite Data for Global Change Research in Developing Countries". Arrangements are also under way to provide travel support to enable scientists from developing countries to attend the 1992 Plenary Meeting in Washington.

The Panel continues to work in cooperation with the United Nations Office for Outer Space Affairs in New York.

XI. EDUCATION

A. Experimental Activities

Three space experiments being coordinated by Students for Exploration and Development of Space (SEDS) involve international student cooperation. Students at the University of Alabama are working with their counterparts at the Imperial College of Science and Technology in London on two Getaway Special experiments aboard the United States Shuttle in 1993. One experiment focuses on heat transfer in microgravity using a fluid phase separation material; the other on determining how foams form in space. The third experiment brings University of Alabama students together with students from the Cheng Kung University in Taiwan, to work on a tethered-satellite experiment to be launched as a secondary Delta payload in June 1993.

The small amateur radio-astronomy satellite SARA, designed and built by French students (see above), is now available to amateur astronomers worldwide.

Under the auspices of the Space Agency Forum for the International Space Year (SAFISY), the French space agency CNES is coordinating an international program of training in the use of satellite technology. Typical applications for developing countries include assessing deforestation, urban pressures on agricultural lands, environment in coastal zones, and geological risks such as active volcanoes and landslides. Participating countries include Colombia, Peru, Morocco, Algeria, Tunisia, Burkina Faso, and five Southeast Asia countries. The first training seminar was held in Bangkok in November; the second in Tunis in December.

B. Teaching Programs

The International Space University held its fourth summer session in Toulouse, France this year, postponing the originally scheduled Moscow summer session to 1993. 130 students from 30 nations attended the session, whose main design project was an international Mars mission. George van Reeth, retiring Director of Administration for ESA and a former IAF president, was selected to take office in January 1992 as the first president of the ISU. ISU's 1991 budget has grown to US$2 million, contributed by 125 sponsors.

The first International Space School was conducted for 14-18-year-old students at the University of Kent in the United Kingdom from 17 August through 7 September. 25 British students from Brunel University's Space School were invited by the Soviet space society Soyuz to a 12-day tour of Soviet space facilities in September, following a 10-day visit by four Soviet students to Brunel in August.

In August 1991 a group of teachers selected from 21 nations met at the International Space Camp, Huntsville, Alabama, United States to draft an International Space Education Initiative stressing the need to introduce space education into all aspects of the educational systems of all countries and to encourage more international cooperation and exchanges.

During 1991 United States space corporations committed large sums to support educational programs ranging from kindergarten through University graduate school. Hughes pledged US$15 million; Rockwell US$5 million, TRW US$4.5 million, Comsat US$1.1 million, and Martin Marietta US$3.1 million.

The first of four videoconferences for teachers run by NASA's Educational Affairs Division during this school year, held in October, focused on space exploration. About 2,000 teachers participated in the two-way discussion with NASA Office of Exploration officials.

The United States National Science Foundation is developing materials for cross-teaching many different science and mathematics disciplines based on the concepts involved in the Search for Extraterrestrial Intelligence (SETI). As part of the International Space Year (ISY) these materials will be translated into the lanquages of interested countries.

Educational videotapes on space science have been produced in Japanese and English by Japan's Institute of Space and Astronautical Sciences (ISAS) for distribution to schools and other public education institutions in Japan and elsewhere in Asia.

The Education Department of the French space agency CNES has developed a new curriculum on Earth observation and remote sensing using kite photography and image processing on personal computers. The curriculum will be presented to educators during a July 1992 international seminar to be held in France as part of the International Space Year.

C. Public Awareness

The Euro Space Center's Space Camp opened on 19 June in Redu, Belgium. Aimed at educating young people in space technology and encouraging them to pursue careers in space, the camp is organized into three age levels for 10 to 18-year-olds to study space science, build and launch small rockets, and experience astronaut training and flight via a simulator.

The global contest for a paper on the subject "Together to Mars," organized by the Planetary Society, has drawn papers from 30 countries. The 20 finalists will attend the World Space Congress in August 1992. A Japanese contest on the theme "The Future of Space for You" elicited 250 papers from high schools all over Japan. The winners will also attend the World Space Congress.

XII. POTENTIALLY ENVIRONMENTALLY DETRIMENTAL ACTIVITIES IN SPACE

The COSPAR Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS) sponsored a symposium on Space Debris at the 1990 COSPAR Meeting in The Hague, during which the latest observational results, such as those from the NASA Long Duration Exposure Facility (LDEF), as well as modeling of space debris orbits and their decay, were discussed in detail. PEDAS is also involved in preparations for the 1992 IAU/ICSU/UNESCO Symposium on Adverse Environmental Impacts on Astronomy, during which the effects of space debris on astronomical observations will be discussed and evaluated.

During the 1992 World Space Congress (COSPAR and IAF Meeting) in Washington DC., PEDAS will co-sponsor, with the International Academy of Astronautics, a symposium on the Chemical Pollution of the Atmosphere, which will be devoted to pollution and modification aspects of the stratosphere, mesosphere, and ionosphere caused by air breathing and space vehicles and by chemical release experiments in space.

CONTRIBUTORS

The report submitted by IAF (Part One) was prepared by Dr. Jerry Grey (for Dr. Karl Deutsch and Dr. Lubos Perek, Co-Chairman of the International Programme Committee for the 42nd IAF Congress), and was approved by Dr. Alvaro Azcarraga, the current President of IAF.

For the report submitted by COSPAR (Part Two), each of the seven Interdisciplinary Scientific Commissions and four Panels of COSPAR contributed a chapter. The following people prepared inputs for their Commission or Panel: Prof. G. Ohring (United States), coordinator for Chapter I; Prof. D. Möhlmann (Germany), coordinator, and Prof. T.C. Owen (United States) and Prof. B.E. Schutz (United States), contributors to Chapter II; Prof. E. Thrane (Norway), coordinator, and Prof. L. Bossy (Belgium), Dr. G. Keating (United States), Dr. J. Lastovicka (Czechoslovakia), Dr. F. Lipkin (Germany), Prof. V.I. Moroz (Russian Federation), Dr. D. Rees (United Kingdom) and Dr. R. Torbert (United States), contributors to Chapter III; Prof. D.J. Southwood (United Kingdom), coordinator, and Dr. D.E. Page (United States), contributor to Chapter IV; Prof. L.E. Peterson, coordinator, and Dr. A.H. Gabriel (France) and Prof. J.L. Culhane (United Kingdom), contributors to Chapter V; Dr. G. Horneck (Germany), coordinator, and Prof. K. Dose (Germany) and Dr. E.A. Ilyin (Russian Federation), contributors to Chapter VI; Prof. M.E. Glicksman (United States), contributor to Chapter VII; Prof. J.B. Zielinski (Poland), contributor to Chapter VIII; Prof. W. Riedler (Austria), coordinator for Chapter IX, assisted by Dr. K. Torkar (Austria); Prof. R.R. Daniel (India), contributor to Chapter X; Prof. S.J. Bauer (Austria), contributor to Chapter XI; Mme. Y. Stevanovitch (Belgium), Editor.

ACRONYMS AND ABBREVIATIONS

AASE II	Airborne Arctic Stratospheric Expedition II
ACSYS	Arctic Climate Systems Study
ADEAS	Advanced Earth Observing Satellite (Japan)
AMI	Active Microwave Instrument
APEX	Active Plasma Experiments
ARCS	Argon Release Control Study
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AXAF	Advanced X-Ray Astrophysical Facility
BATSE	Burst and Transient Source Experiments
BSRN	Baseline Surface Radiation Network
CAT	Clear Air Turbulence
C-CAP	Change Analysis Program (United States CoastWatch)
CCD	Charged Coupled Device
CDS	Coronal Diagnostic Spectrometer
CEC	Commission of the European Communities
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
CELIAS	Charge Element and Isotope Analysis
CEA	Commissariat d'Energie Atomique (France)
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination of Geostationary Meteorological Satellites
CIGNET	Cooperative International GPS Network
CNES	Centre National d'Etudes Spatiales (France)
COBE	Cosmic Background Explorer
COMA	Cometary Matter Analyzer
COMPTEL	Compton Telescope
COMPTEL	Imaging Compton Camera
COSPAR	Committee on Space Research
COSTEP	Comprehensive Suprathermal and Energetic Particle Analyzer
CRAF	Cometary Rendezvous Asteroid Flyby
CRIT	Critical Ionization Test Flight
CRRES	Combined Release and Radiation Effects Satellite
CZCS	Coastal Zone Color Scanner
DMSP	United States Air Force Defense Meteorological Satellite Program
DOD	Department of Defense (United States)
DOI	Department of the Interior (United States)
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DYANA	Dynamics Adapted Network for the Atmosphere
ECS	EOSDIS Core System
EGRET	Energetic Gamma-Ray Experiment Telescope
EIT	EUV Imaging Telescope

EO-IWG	Earth Observation International Coordination Working Group
EOS	Earth Observing System
EOSAT	Earth Observation Satellite Company
EOSDIS	EOS Data and Information System
ERA	Exobiology Radiation Assembly
ERB	Earth Radiation Budget
ERBE	Earth Radiation Budget Experiment
ERBI	Earth Radiation Budget Instrument
ERBS	Earth Radiation Budget Satellite
ERNE	Energetic and Relativistic Nuclei and Electron Equipment
ERS	European Remote Sensing Satellite
ESA	European Space Agency
EUMETSAT	European Meteorological Satellite Program
EURECA	European Retrievable Carrier
EUV	Extreme Ultraviolet
EUVE	Extreme Ultraviolet Explorer
EXOSAT	European X-Ray Observatory Satellite
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FAO	United Nations Food and Agriculture Organization
FIRST	Far Infrared Sub-millimetre Telescope (ESA)
FOC	Faint Object Camera
FOS	Faint Object Spectrograph
FUSE UV	Far Ultraviolet Explorer (NASA)
FY	Fiscal Year
FY-1B	Feng Yun-1B
GCIP	GEWEX Continental-scale International Project
GCM's	General Circulation Models
GDR	Geophysical Data Records
GEOSAT	Geostationary Earth-orbiting Satellite (NASA)
GEWEX	Global Energy and Water Cycle Experiment
GGS	Global Geospace Program
GHRS	Goddard High Resolution Spectrograph
GIG-91	GPS IERS and Geodynamics
GLONASS	Global Navigation Satellite System
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Studies
GOLF	Global Oscillations at Low Frequencies
GOMS	Geostationary Operational Meteorological Satellite
GPCP	Global Precipitation Climatology Project (WCRP)
GPDC	Global Precipitation Data Center
GPS	Global Positioning System
GRID	Gamma-Ray Imaging Device
GRO	Gamma-Ray Observatory
GSFC	Goddard Space Flight Center (NASA)

GSI	Gesellschaft für Schwerionenforschung MBH
GVI	Global Vegetation Index
HEIHE	Heihe River Field Experiment
HIREGS	High Resolution Gamma-Ray and Hard X-Ray Spectrometer
HRV	High Resolution Visible Imager
HSA	Human Serum Albumin
HST	Hubble Space Telescope
IAF	International Astronautical Federation
ICE	International Cirrus Experiment
ICSU	International Council for Scientific Unions
IERS	International Earth Rotation Service
IGBP	International Geosphere-Biosphere Program
ILAS	Improved Limb Atmospheric Spectrometer
IMG	Interferometric Monitor for Greenhouse Gases
IML	International Microgravity Laboratory
INSAT	Indian National Satellite
IPOMS	International Polar Orbiting Meteorological Satellite Group
IR	Infrared
IRAS	Infrared Astronomical Satellite
IRI	International Reference Ionosphere
IRIS	International Radio Interferometric Surveying
ISAS	Institute of Space and Astronautical Science
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climate Project
ISM	Interstellar Medium
ISO	Infrared Space Observatory
ISTP	International Solar Terrestrial Physics Program
IUE	International Ultraviolet Explorer
JERS	Japanese Polar-Orbiting Research Satellite
JGOFS	Joint Global Ocean Flux Study
KRFM	(Russian) Radiometric (thermal) and Spectrometic Measurements
LAGEOS	Laser Geodynamic Satellite
LASCO	White Light and Spectrometric Coronagraph
LDEF	Long Duration Exposure Facility
LET	Linear Energy Transfer
LLR	Lunar Laser Ranging
LIMS	Limb Infrared Monitor of the Stratosphere
MAC	Multi-Aircraft Campaign (NASA/ESA/CEC)
MAP	Middle Atmosphere Program
MDI/SOI	Michelson/Doppler Imager
MGM	Mechanics of Granular Materials Experiment (NASA)
MHD	Magneto Hydrodynamics
MLTCS	Mesosphere-Lower Thermosphere Coupling Study
MOS	Marine Observation Satellite

MSIS	Mass Spectrometer Incoherent Scatter
NASA	National Aeronautics and Space Administration (United States)
NASDA	National Space Development Agency (Japan)
NAVNET	Navy VLBI Network (United States)
NCDC	National Climate Data Center (United States)
NDVI	Normalized Difference Vegetation Index
NEED	Nonmaxwellian Electron Energy Distribution
NESDIS	National Environment Satellite Data and Information Service (NOAA)
NGDC	National Geophysical Data Center (United States)
NHC	National Hurricane Center (United States)
NLC	Noctilucent Clouds
NIMS	Near Infrared Mapping Spectrometer
NMC	National Meteorological Center (United States)
NOAA	National Oceanographic and Atmospheric Administration (United States)
NRC	National Research Council (United States)
NSCAT	NASA Scatterometer
NSSFC	National Severe Storms Forecast Center (United States)
NWS	National Weather Service (United States)
OCTS	Ocean Color and Temperature Scanner
OLR	Outgoing Long-wave radiation
ORCA	Office of Ocean Resources Conservation and Assessment (United States)
OSL	Orbiting Solar Laboratory
OSSE	Oriented Scintillation Spectrometer Experiment (NASA Gamma Ray Observatory)
PEGSAT	Pegasus Satellite System
PMSE	Polar Mesosphere Summer Echoes
POLDER	Polarization and Directionality of the Earth's Reflectances (instrument)
PRARE	Precise Range And Range-rate Equipment
PRISMA	Probing Rotation and Interior of Stars
RAIDS	Remote Atmospheric and Ionospheric Detection System
RFI	Request for Information (NASA)
RFP	Request for Proposal (NASA)
ROSAT	Röntgen Satellite (German X-ray satellite)
SAGE	Stratospheric Aerosol and Gas Experiment
SAMS	Stratospheric and Mesospheric Sounder
SAR	Synthetic Aperture Radar
SAX	X-ray Astronomy Satellite (Italian)
SBUV	Solar Backscatter Ultraviolet Spectral Radiometer
SCOSTEP	Scientific Committee on Solar Terrestrial Physics
SeaWIFS	Sea-Viewing Wide Field Sensor
SERC	Science and Engineering Research Council
SETI	Search for Extraterrestrial Intelligence
SIRTF	Space Infrared Telescope Facility
SLR	Satellite Laser Ranging
SME	Solar Mesospheric Explorer

SMM	Solar Maximum Mission
SMY	Solar Maximum Year
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SPOT	Satellite pour l'observation de la terre TMLF
SRB	Surface Radiation Budget
SSM/I	Special Sensor Microwave/Imager
SSM/T	Special Sensor Microwave/Temperature
SST	Sea Surface Temperature
STEP	Solar Terrestrial Energy Program
STR	Scanning Television Radiometer (GOMS)
STS	Space Transportation System
SUMER	Solar Ultraviolet Emitted Radiation
SUMER	Solar Ultraviolet Coronograph Spectrometer
SWAN	Solar Wind Anistrophies
SWIR	Short-wave Infrared Radiometer
TDRSS	Tracking and Delay Relay Satellite System (NASA)
TIROS	Television and Infrared Observations Satellite
TM	Landsat Thematic Mapper
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TOVS	Tiros Operational Vertical Sounder
TREES	Tropical Ecosystem Environment observation by Satellites (ESA)
UARS	Upper Atmospheric Research Satellite
UCWE	Upward Coupling of Wave Energy
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UnSMP	United States Microgravity Payload
UV	Ultraviolet
UVCS	Ultraviolet Coronograph Spectrometer
VAS	Visible and Infrared Spin Scan Radiometer
VIRGO	Variability of Solar Irradiance
VIRA	Venus International Reference Atmosphere
VLBI	Very Long Baseline Interferometry
VLF	Very Low Frequency
VNIR	Visible and Near-Infrared Radiometer
VOIR	Venus Orbiter Radiometer
VSOP	VLBI Space Observatory Program
WCRP	World Climate Research Program
WF/PC	Wide Field Planetary Camera
WMO	World Meteorological Organization
XMM	X-Ray Multi-Mirror Observatory
XTE	X-Ray Timing Explorer